A-1 A Self-Paced Brain Computer Interface (BCI) Based Point-And-Click System

Xin Yi Yong*, Rabab Ward, Gary Birch

Background and Objective

Point-and-dwell assistive systems have the difficulty of identifying whether the user's aim is to make a selection or to obtain information. To overcome this, our lab looked into the feasibility of developing a point-and-click system that uses an eye-tracker for 'pointing?and a self-paced brain computer interface (BCI) for 'clicking? i.e., selection-making. The first step was to implement a point-and-click system with a simulated BCI switch. Our study investigates: (i) the typing speed the system can achieve with the state-of-the-art BCI system. (ii) the use of eye-trackers in detecting eye blinks and saccades. (iii) how well movement-related EEG trials collected from the experiments can be classified. (iv) the effects of artefacts (ocular, facial muscle, head movement, etc.) on system performance, and how to deal with them.

Methods

A point-and-click eye-tracking system was implemented to operate an on-screen keyboard [1] for text-entry purposes. EEG signals were recorded at a sampling rate of 128 Hz from 15 electrodes positioned over the motor cortex area. EOG, facial EMG, and eye-tracker data were also recorded. Eight able-bodied subjects were asked to point at the desired target using an eye-tracker [2], then attempt a finger extension (detected by a switch) to make a selection. To simulate a real-world BCI system, errors were introduced so that its performance matches the best self-paced BCI system [3] (TPR = 70%, FPR = 1%). The experiment consisted of three to four sessions, each lasting ten minutes. The subjects were asked to type sentences (randomly selected from a database [4]) displayed on the screen. Thirty combinations of bipolar EEG channels were generated and segmented using a sliding hamming window of size 128 samples, with a 93.75% overlap. Eye-blinks and saccades artefacts were detected using the eye-tracker data. Only EEG segments free from these artefacts were processed, using discrete wavelet transform, an autoregressive model of order 8 and power spectral density (1 ?30 Hz). 50 to 200 most discriminative features were selected and classified as either a no-control state (subject not activating the brain switch) and an intentional control state (subject is attempting finger extension). Linear Discriminant Analysis (LDA) was used as a classifier.

Results

For a BCI-based point-and-click system with a TPR of 70% and FPR of 1%, the typing speeds achieved by the subjects varied from 5.8 to 11.3 correct chars/min. Classification of the EEG trials (using LDA 10x10 cross validation) showed TPR ranging from 40.5% to 92.3%, with an average of 64.2% ?22.6%, for FPR = 1%.

Discussion and Conclusions

These results are encouraging. The typing speed can be improved as the subjects were novice eye-tracker and on-screen keyboard users. The eye-tracker was reliable in detecting eye blinks and saccades, and does not require additional EOG channels for artefact detection. By using more advanced signal processing algorithms, the accuracy and system performance can be further improved. Currently, we are studying other types of artefacts commonly arise and how much they affect the system performance. Artefact detection and removal algorithms will be developed to make the system more robust and always functional.

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Keywords

Brain computer interface (BCI), point and click system, eye-tracker, Electroencephalograph (EEG)

A-10 Feedback Information-Theoretic Paradigms for Designing Brain-Machine Interfaces

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Background and Objectives

We have developed an information-theoretic approach to designing brain-computer interfaces that explicitly takes into account both the inherent uncertainty in measurement and interpretation, and the important role of sensory feedback. Our approach was experimentally shown to enhance the overall BCI performance by using binary EEG motor imagery, and was used to remotely teleoperate an unmanned aircraft flying at a fixed altitude. In order to distinguish between left- and right-hand motor imagery, we also built a Common Spatial Analytical Pattern (CSAP) and Hidden Markov Model (HMM) based classifier.

Methods

Our approach views BCI as the means by which the intent of the user is communicated to a prosthetic device to accomplish a task. This communication is enhanced by using sensory feedback, in our case a graphical display. We represent the intent as a sequence in an ordered symbolic language with associated statistical language model. We model the EEG device and the graphical display as a noisy binary channel with noiseless feedback. This abstraction allows the problem of interface design to be reformulated as the problem of deriving an optimal communication protocol using tools from feedback information theory. Such a protocol is provided by the combination of arithmetic coding as a classical method of lossless data compression with posterior matching as a capacity-achieving channel code that uses feedback to avoid the necessity of forward error correction. The classifier uses the group’s newly developed common spatial analytic pattern (CSAP) to extract discriminative signals that capture large disparities for each class by viewing it as a blind-source separation problem. These signals are processed by an HMM to perform classification by belief propagation and to account for the independence between consecutive classifications. A classification occurs at a variable rate when the belief probability exceeds a threshold.

Results

We designed two applications to evaluate our information-theoretic approach: (1) interface for text entry where the intent is an English sentence; and (2) interface for path entry where the intent is a smooth planar curve composed of circular arcs chosen from a finite alphabet. In our experiments with nine able-bodied subjects with limited exposure to EEG motor imagery, the best rates were 6 chars/minute in text spelling and 12.5 arcs/minute in path entry. We also recorded EOG and EMG data to verify that the artifacts were not the enabling factors of the performance. Finally, we demonstrated the feasibility of our approach in the online setting where action needs to be taken while communicating the intent. A human pilot remotely teleoperating a model UAV succeeded in two different target surveillance tasks. We measured the performance of the CSAP-based classifier in a set of experiments with able-bodied subjects and obtained the highest information transfer rate of 60.9 bits/min which is significantly better than the previously reported rate of 37.1 bits/min.

Discussion and Conclusions

We presented an optimal communication protocol which is not only optimal but also can be easily understood and implemented by a human user. This protocol was used in applications where the task can be modeled as a sequence of symbols. We achieved promising performance gain by employing sensory feedback in the optimal way by using tools from information theory and by developing a classifier that provides a promising information transfer rate.

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Keywords

Feedback information theory, electroencephalography (EEG) motor imagery, text speller, path specification, remote teleoperation

A-11 Development of a laryngeal surface electromyographic biofeedback system for an efficient neurally-controlled communication interface

Emily Mugler*, Patrick Rousche, James Patton

Brain-computer interface (BCI) has been applied with increasing frequency and success in recent years for the purposes of neural rehabilitation, augmentation and automated physical therapy. Although there have been significant achievements with repair, replacement and enhancement of motor control and neurological prostheses, similar advancement in the field for communication prostheses has been limited. Current BCI systems for communication have yet to attain reliable, indefatigable control by their users with information transfer rates superior or comparable to rudimentary binary switches. We hypothesize that utilizing non-invasive surface electromyographic recordings (sEMG) of the fine motor movement of the larynx and articulatory muscles could contribute to a robust BCI communication and biofeedback system for multi-purposed applications. Standard and accepted approaches for non-invasive, communicative BCI have utilized semantic, global, and reactionary EEG signals for typographic-style entry. Contrastingly, this approach directly accesses areas corresponding to phonetically-driven language output, potentially resulting in a more efficient and natural synthesis of speech in the presence of an intact recurrent laryngeal nerve and its corresponding motor neurons. sEMG of the peripheral nervous system shares the advantages of non-invasive recordings such as electroencephalography (EEG) without impedance barriers to the electrical signal such as the skull. Additionally, preliminary studies by some research groups demonstrate that even mimed or low-energy “sub-vocal?movement can be capable of sEMG language transcription. By bootstrapping microphone-recorded speech with the filtered LEMG signal (bandpass: 0.3 - 300 Hz) of dictated phonemes and sentences by healthy General American English-accented native speakers and applying a counter-propagation neural network to sEMG recordings, we have derived an encyclopedia of user-independent laryngeal movement corresponding to the International Phonetic Alphabet (IPA). Preliminary results in testing of the system depict robust (>90%) accuracy in categorizing speaker-independent LEMG phonetic results. Current work comprises real-time categorization and phonetic transcription of sEMG output and biofeedback presentation using naive subjects. Short-term goals include providing visual and auditory feedback for improvement of pronunciation, as well as providing visual feedback to hearing-impaired individuals will assist in development of more natural speech; long-term goals for this project include an efficient communication system for individuals that lack speech capabilities but still have intact innervation of the throat.

Keywords

communication BCI, surface electromyography

A-12 Towards a Practical SSVEP based BCI

Gary Garcia Molina*, Danhua Zhu

BACKGROUND AND OBJECTIVES

Focusing of attention on a repetitive visual stimulus (RVS) oscillating at a frequency higher than 3Hz elicits a so-called steady state visual evoked potential (SSVEP). The SSVEP can be more prominently measured from the EEG recorded at occipital sites. BCIs can utilize the SSVEP by presenting to the user a set of RVS oscillating at different frequencies, associating a particular RVS with an application-dependent action, and executing the action corresponding to the RVS which receives the user attention at a particular moment. SSVEP based BCIs require shorter user training and can offer higher information throughput as compared to other BCI types relying on the P300 or motor imagery. In addition, SSVEP based BCIs support independent operation because covert attention to an RVS does also elicit a SSVEP. Deployment of this technology to consumer homes needs to consider several aspects whose assessment constitutes the objective of the research results presented in this paper. In addition to communication bitrate, training duration, operation robustness across time, and optimal electrode location, the user safety and comfort are given considerable attention in our research.

METHODS

Ten healthy subjects participated in weekly recording sessions across six months. SSVEP recordings were performed for different stimulation frequencies ranging from 3 to 60 Hz. The signals were recorded at 32 locations on the scalp including frontal, central, parietal, and occipital locations. The SSVEP response vs. the stimulation frequency was determined and three frequency ranges: low (3-15 Hz), medium (15-30 Hz), and high (30-60Hz) were distinguished. Optimal spatial filters to maximize the SSVEP response were determined for each frequency and recording session to assess: the optimum electrode configuration and its variability across time, frequency, and subject. BCI operation has been assessed by presenting subjects with four RVS under two paradigms. 1) Different stimulation frequency for each RVS and 2) Same stimulation frequency but different phase for each RVS.

RESULTS

The SSVEP response in the high frequency range is considerably lower than in the low and medium frequency ones. However, from user questionnaires it appears that high frequency stimuli are considerably more comfortable. In addition, the risk of photoinduced epilepsy is significantly diminished by using such frequencies. As expected, the optimal EEG spatial filters result in higher coefficients in the occipital area. The coefficients are frequency and subject dependent and vary over time. The time variability is more pronounced in the high frequency range. Only few frequencies in the 30-60 Hz range are able to elicit sufficiently strong SSVEP for BCI purposes. This effectively reduces the communication throughput. To circumvent such limitation, the detection of the stimulation phase was successfully tested with high frequencies. The bitrate was estimated using the confusion matrix during actual BCI operation. The bitrates in the low, medium and high frequency stimulation range from 60-80, 30-40, and 20-30 bits per minute respectively.

DISCUSSION AND CONCLUSION

Our research shows that SSVEP based BCIs can be commercially viable. The use of spatial filters to determine the optimum electrode configuration allows for fast customization. Using high frequency stimulation increases the user comfort while limiting the safety risks. By detecting the phase of the stimulation we circumvented the limitation in the high frequency stimulation range and increased further the user comfort.

A-2 Use of long waves in The Electromagnetic Spectrum in development of passive areas of brain

Mohammad Gouran-savadkoohi*

Background and Objective:

Congenitally deaf poeple or poeple with ambilodypia have the problem of the nonfunctioning parts of the brain and probabaly under production of the the synatcal interactions in these areas stem cell researchs are undergoing through this probabaly but the is a neglegted part of the sience which is evolving seperatly ie Ophthalmology the use of Laser ,in the new treatments ,is basically a result of use the slite lamp which produces an optical cross section with a capacity to change the angle ,width and length and intesity of light beam ,computerized automated primeter which use test lights with varing brightness and size and Numerical printout of threshold deriverd useing the static method of computrized perimetry is compared with normal subjects ,Confocal scanning Laser tomography II a device which use CT sections OCT which uses 820nmwave lenght light EOG ,VER and ..... know that more ore less the region of the brain responsible for our hearing ,visual cortex and memory is some how idendified why we are not eveluating the regions by internal stimulators with LONG wave lights http://hyperphysics.phy-astr.gsu.edu/Hbase/quantum/imgqua/scheqcon.gif please see application of the material with the aplication of the wave and http://hyperphysics.phy-astr.gsu.edu/Hbase/imgmod2/wf.gif and the thermal energy which is the base of the working brain is drived form ATP ....along with appropriate current of electrical of electromagnetic waves .tring to apply one these waves or at least mesearing the field in normal poeple will change the our concept and treatment .

Results

http://www.ask.com/bar?q=hyperphysics&page=1&qsrc=121&dm=all&ab=1&u=http%3A%2F%2Fhyperphysics.phy-astr.gsu.edu%2FHbase%2Fhph.html&sg=hyymVST0l2TX3M7Jjx5jFkFx%2Bqqa21qJZo3Qr1f%2Bdv0%3D&tsp=1261619249029 synapic transmissions are drived from combination of these chemical and thermal events resulting electrical event so why we are looking at high voltage Xrays when :http://hyperphysics.phy-astr.gsu.edu/Hbase/solar/picsol/galcolt.jpg communication is better in lower f but longer wave lenght .please help me if you find this concept intresting

A-3 P300 and SSVEP based Brain-Computer Interface for a Virtual Smart Home Environment Control

Günter Edlinger*, Gunther Krausz, Massimo Mecella, Christoph Guger

A brain-computer interface (BCI) is a new communication channel between the human brain and a computer without using any muscle activities. Applications of BCI systems comprise communication, restoration of movements or environmental control. BCI experiments for navigation in Virtual Reality (VR) were done so far based on (i) synchronous BCI and (ii) asynchronous BCI systems. A synchronous

BCI analyzes the brain patterns in a predefined time window. This means if the subject imagines e.g. foot movement it can move forward, if it imagines right hand movement it can turn right and with left hand movement it can turn left. The asynchronous BCI analyzes the EEG signal continuously and if a specific event is detected then the control signal is generated. If the subject imagines e.g. foot movement it is moving forward as long as the foot imagination is detected. Both systems are currently limited to 1-3 degrees of freedom and therefore a fast control mechanism cannot be realized. Within this study we propose a combined P300 and steady state visually (SSVEP) evoked potential based BCI system for controlling a smart home in a VR implementation with a high accuracy and a high degree of freedom. The system shows 20 to 45 selectable commands on a computer screen. The commands are highlighted in a random order. Whenever a target command is flashing up, a P300 response can be detected from the ongoing brain activity and a control command is initiated. However, some command groups like “move right, move left, move forward, move backward or stop?do not need an extended user interface. For such command groups a SSVEP based BCI approach was implemented consisting of light sources flickering at user selectable different frequencies. The subject simply watches one of the flashlights. Specific commands are connected with the different flickering lights. The user selected command can be detected as the same flickering frequency can be found in the brain activity. A further big advantage of the implemented approach is that the so-called zero class (no command is selected) is reliably detected. Hence even a direct control of a device can be realized. If the subject does not want to control the device then he/she simply ignores the flashing lights. First results of 3 subjects show that the concept of combined P300 / SSVEP-based BCI enables a high performance and accuracy (83% to 100%) after only 10 minutes of training. More generally the work allows realizing both i) a synchronous goal orientated control system using the P300 interface satisfying the intention of the user more naturally, e.g. sending the command grasp a glass of water; here one can select a command from a large command base and ii) a reliable more direct control of devices based on an asynchronous SSVEP interface; here just a few commands can be selected with very good performance including zero-class detection.

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Keywords

P300, SSVEP, brain-computer interface (BCI), Virtual Reality, Smart-Home

A-4 Analogue Mouse Pointer Control via a Online BCI using SSVEP

John Wilson*

Background and Objective

The Steady State Visual Evoked Potential has proved a robust paradigm for viable Brain-Computer Interfaces with high transfer rates. Discrete analysis techniques are appropriate for applications that are inherently discrete in nature, such as selecting numbers on a keypad to dial a telephone number or letters from an alphabet to spell words. However the most prevalent human-computer interface is the point and click of the mouse pointer, an intrinsically analogue control method. Applying common discrete control methods to analogue interfaces results in a cumbersome, frustrating experience for the end user and common performance measures become meaningless. We introduce a novel online BCI for fully analogue four directional mouse pointer control in which a binary decision is never made. The system is tested by six subjects through an online game moving a reticule to hit targets and compared to a traditional discrete system.

Methods

The stimulator/feedback engine contained a pointer reticule surrounded by four distinct reversing gratings. The user could move the reticule around the screen by simply attending the stimulus corresponding to the direction they wished to move. Single cycle lengths of EEG corresponding to each of the four stimuli were sequentially extracted and presented to an FFT and the complex results used in significance tests for discrete control and to calculate phase coherence for analogue control. At each decision step discrete control resulted in a cursor movement of 0-1 pixels whereas analogue control provided a range of movement from 0-5 pixels. Six subjects were required to complete four distinct 'Games?for both control modes requiring the movement of the target reticule over a set of subsequently appearing targets. Pointer trajectorys and time taken were recorded .

Results

Analogue Control took the least time to complete 17 out of a possible 24 games across all subjects. The average time to complete a game using Analogue Control was significantly less ($p < 0.01$) than using Discrete Control. A wrong move was counted as a move in x or y direction that resulted in the pointer being further away from the current target than on the previous iteration. Analogue Control had a significantly higher ($p < 0.01$) percentage of wrong moves than Discrete Control.

Discussion and Conclusions

There was significant difference in time taken to complete a game between Discrete and Analogue Control but the latter suffered from significantly higher percentage of wrong moves. It is clear that the higher sensitivity of Analogue Control is more susceptible to contamination from other stimuli or by ongoing brain rhythms overlapping with stimuli frequencies compared to the statistical test threshold employed in Discrete Control. To address this a further control method combining the high threshold for initial movement of Discrete Control and the proportional movement of Analogue control was explored with excellent results . It is important to always relate the control method of the BCI to the application at hand. In this way a BCI can be constructed that truly fits the application rather than augmenting applications to fit the BCI.

Keywords

SSVEP Analogue Online Pointer Phase Coherence

A-5 Towards communication in the complete locked-in state: an electrical semantic conditioning paradigm.

Daniele De Massari*, Adrian Furdea, Tamara Matuz, Carolin Ruf, Jeremy Hill, Sebastian Halder, Niels Birbaumer

Keywords: classical conditioning, completely locked-in state, electrical stimulation.

Several neurological diseases such as amyotrophic lateral sclerosis (ALS), muscular dystrophy or high spinal cord injury may lead to severe or complete motor paralysis, making communication hard or even impossible. These patients may develop the completely locked-in state (CLIS) in which all motor control and thus the ability to communicate is lost. The unsuccessful efforts to restore communication by means of Brain Computer Interface (BCI) in CLIS patients could be explained by the extinction of output directed and goal oriented thoughts, which could lead to a state incompatible with operant learning. Consequently a classical conditioning rather than instrumental-operant learning paradigm, requiring less attentional resources and voluntary efforts could represent a better alternative for people in CLIS. Within this project we propose a classical semantic conditioning design to allow basic yes/no communication. More precisely, we indented to condition cortical responses to the trueness of a sentence irrespective of the particular constituent words and letters or sounds of the words. As unconditioned stimulus (US) we used short electrical stimulation consisting of 1-ms electrical pulse delivered over the left thumb whose intensity was individually set according to a subjective scale. True and false sentences were presented through earphones, subjects being asked to think on 'Yes?and 'No? according to the type of the sentence. True sentences, and thus thinking on 'Yes?(CS+) were immediately followed by US whereas false sentences (thinking on 'No?= CS-) was never paired with the US. Each subject underwent three sessions, the first two in consecutive days and the third session one week later, which comprise three blocks. Each block consisted of 50 true and 50 false sentences: in the first block CS+ were paired with the US, whereas in the second and third block 10, respectively 15 CS+ called extinction trials were not coupled with the US. The last session included a forth block with 40 sentences (20 true and 20 false) not followed by any stimulation. The electroencephalogram (EEG) was recorded from 32 electrodes. As reported in the literature, the conditioned response has not necessarily to be identical to the reaction elicited by the US. Therefore, to distinguish between 'Yes?and 'No?thinking, the classifier was trained and tested on extinction trials. The first 500ms segments relative to the end of the sentence were low-pass filtered, down-sampled and used as input features for the Stepwise Linear Discriminant Analysis classifier. Preliminary data of two healthy subjects has been collected and processed providing incentives for future acquisition and application on more healthy subjects and ALS patients. The accuracy on Yes/No discrimination ranged from 60-70%.

Results

For a bigger healthy sample and first data of ALS patients will be presented. The ultimate goal of BCI research is to provide a non-muscular communication channel for individuals who are no longer able to communicate by any means due to severe physical impairment. According to this main aim, this study represents an attempt to investigate the applicability of a semantic conditioning paradigm in a BCI setting that could enable yes/no communication for people in CLIS without the need for operant learning.

Support

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A-6 Investigation of the Stability of SSSEP Elicited by Vibro-Tactile Stimulation

Christian Breitwieser*, Christa Neuper, Gernot Mueller-Putz

Background and Objective

In general, steady-state evoked potentials (SSEPs) [1] have already been well explored in the electrophysiology literature, and are often used in brain-computer interfaces (BCIs) [2]. Steady-state somatosensory evoked potentials (SSSEPs) [3, 4] can be used in BCIs for communication and control without any movement, purely by focusing on tactile stimuli applied e.g. to the index finger of the left and right hand [5]. The aim of this work is to investigate the stability of such signals to ensure constant results over longer time periods. Vibro-tactile stimulation of five fingers on the right hand is used for generating SSSEPs, using a self-made stimulation device. We also explored the emergence of a person independent tuning curve based on SSSEPs.

Methods

A 200 Hz sine wave was modulated with a rectangular signal [6] to stimulate the Pacinian corpuscles. The frequency range of the modulation signal was between 17 and 35 Hz. Stimulation was applied in 2 Hz steps, resulting in 10 different stimulation frequencies. Fingers were never stimulated consecutively and every stimulation frequency was applied at every finger 40 times. The study was divided in two sessions with at least two weeks between the two sessions. Every session was separated into 20 runs to reduce the burden on the subjects. To avoid external influences [7], all subjects listened to sounds of the sea during the whole experiment. A visual distraction on a screen (subjects were told to count red marked characters) was presented to the subjects to prevent focusing on a specific finger. EEG was recorded using three bipolar channels over C3, Cz and C4. Trials with EMG artifacts were removed manually before data processing. Discrete fourier transform computations were performed to check data for amplitude increases during stimulation in the respective frequency range. Bandpower computations were made to describe a bandpower increase compared to a given reference period. Nine subjects participated in the study with an average of 28 days between the measurements to investigate a possible change in their SSSEPs over time.

Results

Six out of nine subjects showed a significant bandpower increase, independent of the stimulated finger. The emergence of a tuning curve, similar at all five fingers, could be shown. Resonance frequencies were person dependent. A significant increase only arose over C3 , whereas all subjects showed a good stability of bandpower increase over time.

Discussion and Conclusions

Vibro-tactile stimulation elicited significant EEG changes in most subjects. Due to the simple design of the experiment, finger pressure on the stimulation unit could not be measured, and inadequate finger pressure may explain why three subjects did not show significant EEG changes. Because of the long duration of the experiment, only two sessions were performed. So a single screening session is enough to determine optimal frequencies for each subject, since they can be considered stable over time.

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Support

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A-7 How much learning is involved in BCI-control?

Andrea Kübler*, Donatella Mattia, Harry George, Benaya DORON, Christa Neuper

Background and Objective

Experiments with animals and humans starting in the late sixties demonstrated that physiological functions that were believed to be autonomous, such as glandular responses, blood pressure, and the electrical activity of the brain (EEG) could be braught under voluntary control via operant conditioning (1,2). After it has been repeatedly shown that subjects could produce clearly distinguishable brain responses on command the idea was at hand to use this ability for communication in people who are in the so-called locked-in state with only residual muscular movement left for communication (3,4). In contrast to the neurofeedback approach which involves learning to control a component of the EEG, the machine learning approach aims at detecting patterns of activation in the brain that can be readily produced by the individual (5). Several authors claim that BCI control consitutes a skill (6,7), but a skill requires learning and improvement with practice (8). With the here presented review of BCI studies we were aiming at answering the following questions: (1) how much evidence for learning is provided in BCI studies, (2) how is the course of learning with a BCI, and (3) how stable is performance over time.

Methods

We performed an exhaustive literature review beginning in the late sixties up to now. Search terms were e.g., brain-computer interfaces, neurofeedback, self-regulation, slow cortical potentials, P300, SMR, SSVEP, SSSEP in various combinations. We restricted our review to non-invasive and ECoG studies in humans. EEG, fMRI, MEG, and NIRS were included as a measure of brain activity.

Results

First analysis of a subset of studies (N=137) revealed that in most studies which report online results motor imagery is used for BCI control. Most studies that involved long term training with severely impaired patients relied on slow cortical potentials. The vast majority of studies comprised healthy subjects who typically participated in 1-4 BCI sessions. Although it is often stated that „individuals learned to control the BCI?and „performance improved with time?learning curves are hardly ever presented. Only few studies conducted trials long enough for learning to occur. In such studies it can be seen that learning to control a BCI either follows the typical power or a linear trend.

Discussion and Conclusions

We cautiously conclude that most BCI studies or BCI approaches do not involve human learning. Those which do, rely on neurofeedback to achieve self-regulation of the SMR- or SCP amplitude. In some of those studies performance followed a power trend indicating strong improvement of performance at the beginning of training followed by asymptotic performance with practice. The linear trend indicated constant, slow learning more often seen in patients. The ability to control a BCI appeared to be stable over time even when motor impairment increased. In further studies it could be investigated whether control of such BCIs that rely mainly on pattern recognition could be improved with practice and how both, the human and machine learning approach could be combined to achieve maximum performance also in individuals with motor impairment.

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Keywords

BCI, learning, performance, skill

A-8 Self-paced training of an asynchronous brain switch

Teodoro Solis Escalante*, Gert Pfurtscheller, Christa Neuper

BACKGROUND AND OBJECTIVES

Setting up a BCI typically includes training a classifier from EEG signals recorded during cue-paced sessions. In this work, we propose training an asynchronous brain switch based on motor imagery (MI) using data from self-paced motor execution (ME) experiments.

METHODS

Six healthy volunteers (naïve, 26? years) participated in this study. We recorded brain activity from a single Laplacian derivation over site Cz. Surface electrodes at the tibialis anterior muscles of both legs recorded the activity from those muscles. Participants performed brisk dorsiflexions of both feet at free will during two sessions of 6 min each. Two sessions of 2 min each provided data for a no-control class: EEG at rest, before and after the self-paced sessions. EEG recordings were triggered to form trials: (i) 4s before and after ME offset, and (ii) randomly for the resting recordings. Features were computed as the logarithmic band power. A pair of running classifiers (Fisher's linear discriminants, LDAs) revealed the most discriminative frequency band and the best time point for classification of resting state EEG and movement-related (de)synchronization. Another LDA (10 x 10 cross-validated) provided feedback (jump action of a videogame character) during cue-paced sessions using ME and MI (2 sessions each). Two volunteers showed no discriminative features and did not participate during the feedback sessions. All data were analyzed offline as follows. The DSLVQ analysis was used to search for the best frequencies to discriminate between self-paced recordings and a new no-control class. An offline LDA was obtained and applied to the cue-paced sessions. This process was repeated 2 times, changing the data for the no-control class from EEG during actual movement to data randomly selected from the resting state EEG. Feature selection and classifier training for the offline analyses were completely automatic.

RESULTS

Online: Classification accuracy (ACC) was 86?% for training (without feedback), and 76?1% for ME and 53?3% for MI sessions with feedback. Only one participant was able to imagine foot movements (ACC 73%). The average maximum error rate was 29?7% when we classified resting EEG recordings. Offline (reference during actual movement): ACC was 90?% for training, 89?3% for ME and 53?0% for MI. Error rate 31?9%. Offline (reference resting state EEG): ACC was 90?% for training, 86?2% for ME and 59?4% for MI. Error rate 33?1%.

DISCUSSION AND CONCLUSIONS

We have shown that it is possible to train a brain switch with the EEG recordings from a self-paced motor task. This classifier can be used to provide feedback for MI training of naïve users. The offline analyses indicate that the DSLVQ is better at identifying relevant features than the running LDA method, and thus, DSLVQ allows for a better classifier generalization. Noteworthy, classification accuracy is independent of the data used for the no-control class. In this study, the participants performed real movements; however, with a complete description of the resting EEG, imaginary movements could be detected [2]. Detection instead of classification will be tested in following studies.

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KEYWORDS

Event-related synchronization, brain switch, self-paced, beta rebound, detection instead of classification.

A-9 Toward BCI Wizard - best BCI approach for each user

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Toward BCI Wizard - best BCI approach for each user Ivan Volosyak, Diana Valbuena, Christoph Guger, Jan Ehlers, Axel Gräser Institute of Automation, University of Bremen, Otto-Hahn-Allee 1, 28359 Bremen, Germany g.tec Medical Engineering GmbH, Herbersteinstrasse 60, 8020 Graz, Austria E-mail: volosyak@iat.uni-bremen.de www: http://www.brain-project.org The EU-project BRAIN (ICT-2007-224156) aims at developing practical assistive tools to users with impaired communications due to an illness or injury (e.g. brain or spinal cord injury and stroke) via a Brain-Computer Interface (BCI) which enables communication by utilizing voluntary mental activities. BRAIN will improve BCI reliability, flexibility, usability and accessibility while minimizing the dependence on outside help. These improvements will involve upgrades to all three main components of a BCI system: signal acquisition, signal processing and application. Modern brain-computer interface (BCI) systems use different types of neural activity for control. Most BCI systems only allow the customization of very few parameters and focus only on one type of BCI approach. Many articles reported that a certain BCI did not work for some users (so called BCI illiteracy). We are introducing the BCI wizard as a system that automatically identifies key parameters to customize the best brain-computer interface for each user. With a BCI wizard it is possible to develop an interface that relies on the best mental strategy for each user and therefore makes the difference between an ineffective system and a working BCI. This work presents a preliminary study that aims to develop a BCI wizard exploring the three most effective BCI approaches (P300, SSVEP and SMR). These three types of non-invasive BCIs were tested and evaluated in a group of 14 healthy subjects. All subjects completed all three tests in one session and at the end of the experiment they chose their preferred approach. For P300 and SSVEP BCIs a spelling application was used and the user was asked to spell three words. For the SMR approach, the user was asked first to execute and then to imagine foot movement to control the vertical position of a cursor.

Results

Results showed that all subjects could communicate with the P300-based BCI with an accuracy above 69% (5 reached 100% accuracy), 10 out of 14 subjects could effectively use the SSVEP-based BCI (2 reached 100% accuracy). No subject was able to use the SMR-based BCI only with movement imagination during the first session, but the mean accuracy for movement execution was 83% (3 reached 100% accuracy). Although all subjects were able to use the P300 based BCI, the SSVEP approach was chosen by 6 subjects as preferred BCI paradigm. The performance data show that using different approaches, a BCI system could provide effective communication for most subjects. The vote for a preferred paradigm is yet bound to be subjective and the results need to undergo a detailed analysis. The further BCI research shall be extended to the development of friendly, straightforward wizard that will walk each user through a series of tests to determine optimal parameters. This document is a collaborative effort of Institute of Automation, University of Bremen, Germany and g.tec Medical Engineering GmbH, Austria. This research was supported within the 7th European Community Framework Program by the EU ICT grants BRAIN (ICT-2007-224156) and by a Marie Curie European Re-Integration Grant RehaBCI (PERG02-GA-2007-224753), SM4ll and Presenccia.

Keywords

BCI Wizard, Brain-Computer Interface (BCI), Electroencephalogram (EEG), SSVEP - steady-state visual evoked potentials, P300 Potential (P300), SMR - sensorimotor rhythms

B-1 Variability and nonstationarities in Brain Computer Interfaces

Linsey Roijendijk*, Jason Farquhar

Background and objective

A well-known issue in Brain Computer Interface (BCI) research is the large degree of variability in the measured signals. Variations between users, between sessions, and within sessions (nonstationarities) occur [1,2]. These can be caused by many factors such as psychological factors (e.g., fatigue, mood), physiological factors, change of task involvement (offline versus online task), user learning, or measurement artifacts and noise. To achieve and maintain good BCI performance, a BCI must be able to adapt to these variations. In order to build a BCI, which can adapt to these variabilities, we first need to understand their importance and properties. Therefore, we have gathered a dataset, which allows us to systematically investigate five different types of variability, namely inter-user variability, inter-session variability, user learning, feedback-dependent variability and signal nonstationarities.

Methods

We conducted an Electroencephalography (EEG) experiment using motor imagery as mental BCI task. Subjects had to execute or (kinesthetically) imagine sequential finger movements with the left and the right hand onto a metronome ticking every 300 ms. A metronome was used to ensure that every subject was performing the same task at the same rate. To measure inter-session variability and user learning effects each subject participated in at least two sessions. A session contained blocks with actual and imagined movement without feedback. To look at feedback-dependent variability, blocks with two different types of feedback were included; namely, epoch feedback (‘right?’wrong?at the epoch end) and continuous feedback (basket game). Finally, to measure signal nonstationarities each session was relatively long (more than three hours). Besides 64 electrode EEG recordings, electro-oculographic and electromyographic activity were measured. So far 8 inexperienced subjects have been measured.

Results

Classification performance based on classification of the power in the range from 7 to 30 Hz was determined using feature selection and classification algorithms as described in [3]. Between users the classification performance varied between 53 and 99 percent, with an average of 68 percent. Inter-session classification performance variations were between 1 and 17 percent and no effect of user learning was found. Furthermore, no significant classification accuracy differences among feedback types were found. Additionally, nonstationarities were found.

Discussion and Conclusions

A multi-session motor imagery EEG dataset was collected to investigate variability and nonstationarity. Preliminary analyses revealed high variability in classification performance between users, between sessions and within sessions. No clear results were found yet about user learning and feedback dependent variability. In the near future more subjects will be measured and they will participate in more than 2 sessions to give a better characterization of user learning. Further, the recorded dataset will be explored in more depth to achieve a better understanding of variability in BCIs, e.g. by investigating how the location and the frequencies of the motor imagery signal change. In the near future we intend to release this dataset as a publicly assessable resource to all BCI researchers interested. Once there is a better understanding of the variability this knowledge can be used to increase BCI performance.

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Keywords

EEG variability, BCI nonstationarity, motor imagery

B-10 Automated feature filtering for BCI sequence labelling

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When considering asynchronous BCI, the aim of a BCI system is to provide a label to each EEG sample in order to provide information regarding whether the subject using the BCI tries to produce some signal commands. Many of the current approaches use machine learning techniques for labelling the EEG and as such, they use a single sample (the one to label) for taking a decision. However, since EEGs are by nature sequential and dynamic, it could be interesting to consider the neighborhood of that sample to take a decision. In other words, we would like to provide a label to the sample based on a time-filtered version of the samples. The problem we address in this work is the problem of automated selection of the filter coefficient in a large-margin context. The framework is the following : we want to obtain a sequence of labels from a multichannel time-sample of a signal or from multi-channel features extracted from that signal. We suppose that the training samples are gathered in a matrix $\X\in\dbR^{N\times d}$ containing d channels and N samples. $\X_{i,j}$~is the value of channel~j for the i^{th} sample. The vector $\y\in\{-1,1\}^N$ contains the class of each sample (note that in a multi-class context, we will consider a one-against-all approach). We define the filtered data matrix $\Xf$ by: \begin{equation} \label{eq:1} \Xf_{i,j}=\sum_{m=1}^f ~ \F_{m,j} ~ \X_{i+1-m+n_0,j} \end{equation} where the sum is a unidimensional convolution of each channel by the filter in the appropriate column of F. n_0 is the delay of the filter, for instance $n_0=0$ corresponds to a causal filter and $n_0=f/2$ corresponds to a filter centered on the current sample. From this definition, we have the following linear decision function based on filtered samples \begin{equation} \label{eq:decisionsigsvm} f_F(i,\X)=\sum_{m=1}^{f}\sum_{j=1}^{d}\w_j\F_{m,j}\X_{i+1-m+n_0,j}+w_0 \end{equation} where $\w$ and w_0 are the parameters of the linear SVM classifier corresponding to a weighting of the channels. By dissociating the filter and the decision function weights, we expect that some useless channels (non-informative or too noisy) for the decision function get small weights. Indeed, due to the double weighting $\w_j$ and $\F_{.,j}$, and the specific channel weighting role played by $\w_j$, this approach is able to perform channel selection. The parameters $\{\w_i,F\}$ of the decision function given in Equation (\ref{eq:decisionsigsvm}) can be obtained by minimizing a regularized squared Hinge loss which considers the above loss function. The so-defined objective function (\ref{eq:svmopt}) is differentiable and provably non-convex when jointly optimized with respect to all parameters. However, J_{FSVM} is differentiable and convex with respect to $\w$ and w_0 when F is fixed as it corresponds to a linear SVM with squared hinge loss. Hence, we can solve the problem by means of a gradient descent algorithm on F with $\w$ and w_0 being optimal at each F. We test our method on the BCI Competition Dataset 5. The problem is to obtain a sequence of labels out of brain activity signals for 3 human subjects. The data consists in 96~channels containing PSD features and the problem has 3~labels (left~arm, right~arm or feet). The regularization parameters are tuned using a grid search validation method on the third training set. We compare our method to the best BCI competition results (using only 8 samples) and to the SVM without filtering. Test error for different filter size f and delay n_0 may be seen on Table \ref{tab:bcidataset}.

Results

Results show that one can drastically improve the result of the BCI competition (up to 5%) by using longer filtering with causal filters ($n_0=0$). Note that our Filter-SVM approach outperforms an averaging filter and a SVM (Avg-SVM). We have proposed a method for automatically learning a filter adapted to some data at hand. By means of such approach, we are able to considerably reduce the labelling error on a BCI competition dataset problem and interestingly, we note that by allowing non-causality, we can further improve performances. The latter is an interesting point that worths to be investigate further. Indeed, one may ask at which extent non-causality would be allowed in a BCI interface if labeling performance can be increased.

B-11 Benchmarking common BCI algorithms for fast-paced HMS applications

Johanna Wagner*, Klas Ihme, Matti Gaertner, Christian Kothe, Thorsten Zander

BACKGROUND AND OBJECTIVE

Methods of statistical machine learning have recently proven to be very successful in contemporary brain-computer interface (BCI) research based on the discrimination of electroencephalogram (EEG) patterns. Yet, the field is still lacking a large-scale objective comparison as most methods have been tested with small sample groups only. Hence, this study aims at comparing and evaluating the performance of a selection of state-of-the-art BCI algorithms. Furthermore, there is still a lack of publicly available EEG data sets that are applicable for the comparison of BCI methods . One major contribution of this study is therefore the acquisition and publication of EEG data from 43 naive subjects recorded in an executed-movement scenario. This context lends itself to generalizations of BCI performance in similar use cases in human-machine systems (HMS) giving upper performance bounds for these applications.

METHODS

The data basis consists of 32-channel-EEG, electrooculogram, electromyogram, noise level and ambient temperature data measured under highly controlled conditions. An experimental session consisted of 650 trials in which subjects were instructed to press a left (or right) key after the letter L (or R) was displayed. An inter-trial interval of 1000 ms was chosen to make the results applicable to more general fast-paced HMS-like scenarios. Common feature extraction methods and classifier models were compared for (1) event-related-desynchronisation (ERD) and (2) readiness potential (RP). As feature extraction methods , we chose logarithmic band power (logBP), common spatial patterns (CSP) and spectrally weighted CSP (specCSP) for the former and slow cortical potential (SCP) pattern matching as well as CSP for SCP for the latter. Classification was accomplished with linear discriminant analysis (LDA), quadratic discriminant analysis (QDA), regularized LDA or QDA (rLDA, rQDA) and support vector machines (SVMs). The primary performance evaluation measure was the offline cross-validation error rate.

RESULTS

Noticeable, classification performance of the ERD-based algorithms was significantly worse than for the SCP-based ones. For the ERD the more complex feature extraction methods CSP and specCSP outperformed the logBP-method. The best feature extraction for the RP was the pure SCP algorithm. Interestingly for classification on SCP, the simplest classifier model, LDA, was not significantly worse than the other classifiers and significantly better than the (unregularized) QDA.

DISCUSSION AND CONCLUSION

Results of the ERD-feature extraction methods show that algorithms learning subject-specific spatial projections of the EEG-signal performed better on data with high inter-individual variability. Considering RP-features, it seems that the data is linearly separable as the non-linear classifiers did not perform better than simple LDA. This study presents evidence that SCP-based algorithms bear good prospects for fast-paced active control scenarios. Moreover, it suggests that linear classification models are suitable for motor BCI features. All data is available for public access on our website www.phypa.org. We highly encourage other researchers to join our benchmarking approach ?download data, test their algorithms and use the website as hub for the publication of data.

KEYWORDS

BCI-algorithms, classification models, public data hub, feature extraction methods , Human-Machine Systems

B-12 Reliable Identification of Mental Tasks Using Gaussian Models of Time-Embedded EEG and Sequential Evidence Accumulation

Chuck Anderson*

Background and Objective

The literature includes many algorithms for asynchronous EEG feature extraction and classification, but such algorithms are often computationally expensive and the identified features are not consistently present in EEG signals. We address this limitation here in several ways. First, common feature transforms, such as the fourier transform, are replaced by a simple time-embedding of EEG. It is shown that simple classifiers based on Gaussian models can discriminate time-embedded EEG recorded during the performance of different mental tasks. To overcome difficulties due to inconsistently present patterns in EEG, evidence from consecutive classifications must be combined and BCI decisions must be delayed until sufficient evidence is accumulated.

Methods

A subject performed 50 repetitions of each of four mental tasks: imagined right hand movement, imagined left foot movement, counting backwards, and imagined tumbling of computer screen in three dimensions. Each repetition was performed for five seconds. EEG was recorded from 19 channels at 256 Hz using a Mindset EEG amplifier connected to a workstation via a SCSI port. Samples from the first 30 repetitions were used to train the classifier, repetitions 31-40 formed the validation set used to pick the best classifier parameters, and repetitions 41-50 were used as the test set. An artifact removal filter was constructed using the maximum noise faction transform [1] from the first two trials of every task and then applied to all trials. The time-embedding representation of each channel was nine dimensional with a delay of five. A quadratic discriminant analysis (QDA) classifier was trained on this representation of the training repetitions. Evidence from consecutive classifications was combined using a variant of the multihypothesis sequential probability ratio test (MSPRT) [2] to combine the mental task likelihoods produced by QDA over multiple samples.

Results

The fraction of test samples classified as each task were as follows. The counting task was most reliably detected, at 92% of test samples correctly classified. The imagined hand task was correctly classified at an 87% rate and the imagined foot task at a rate of 82%. The imagined visual tumbling task was not as reliably classified, at 68% with most wrong samples being classified as the imagined counting task. MSPRT parameters were set so that a decision was made approximately every second. In most cases, confidence was high before one second of data was observed, but in use a subject would probably not be able to choose items on a computer menu faster than once a second. These methods are being implemented in our open-source BCI software [3].

Discussion and Conclusions

The result that reliable classification can be obtained using simple data transforms and classifiers, such as time-embedded and QDA, is surprising. The structure of the learned Gaussian models will be analyzed to determine what aspects of the time-embedded data lead to successful classification. Also, experiments are being repeated with additional subjects and with other mental tasks. The computationally simple signal transform and classification procedures warrant consideration for other BCI paradigms, such as the P300-based speller.

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Keywords

mental tasks, time-embedding, quadratic discriminant analysis, evidence accumulation

B-13 Non-intentional control for asynchronous BCI: A statistical approach

Michele Tavella*, Serafeim Perdikis, Robert Leeb, Jose del R. Millan

Background and Objective

Applying Brain Computer Interface (BCI) technology in real-world applications demands identification of brain patterns in an asynchronous manner in order to achieve a natural way of humancomputer interaction. So far, most of the existing BCI systems are operated under a synchronized, cue-based paradigm, imposing time and speed constraints on the subject, as well as forcing him/her to be continuously under BCI control with no possibility to voluntarily relax or shift his/her attention to other activities. Identifying those non-intentional control (NIC) intervals is an open challenge attracting growing interest in BCI [2]. Our BCI system is based on an asynchronous control paradigm, where the user learns to voluntary modulate EEG oscillatory rhythms by executing different mental tasks. This abstract refers to the statistical machine learning techniques applied under this framework to enable accurate classification of the mental tasks and identification of NIC.

Methods

Three blocks in our mental imagery-based BCI are responsible for enabling NIC and multitasking capabilities to the user: a) stable subject-dependent feature selection b) sample rejection on the classifier output and c) evidence accumulation over time. Feature selection is based on Canonical Discriminant Spatial Patterns (CDSP) [1] aiming at selecting those features that are the most discriminant and stable across recording sessions for a specific subject. While on-line, a rejection threshold is set on the probability distribution over the mental classes emitted by the classifier, thus filtering out decisions with low confidence. Last but not least, surviving decisions are not immediately translated into commands, but rather treated as temporary evidence on the executed task and accumulated using an exponential smoothing probability integration framework. A command is finally delivered by thresholding the integrated probability distribution. The desired effect of the described approach is that although the “unknown?state is not explicitly encoded in the classifier and the system is always monitoring and classifying the subject’s brain patterns, he/she is generally able to avoid delivering unintentional commands while occupied with tasks other than controlling the system, such as talking to fellows, without degrading delivery speed and accuracy of intentional commands.

Results

A preliminary study with 3 subjects supports the above mentioned claims. The subjects were instructed to operate the BCI during an online experiment including 2 NIC trials (20 seconds each) and 4 intentional control (IC) trials (10 seconds each) per run. For each run we measured the average number of intentionally delivered commands, both correct (9.8) and erroneous (0.30), as well as the average number of non-intentional decisions during NIC (4.1). During NIC trials, subjects had not to perform any activity. We can see that, on average, people can deliver almost double mental commands during IC than during NIC. Furthermore, the number of errors during IC is negligible. It is also worth noting that one of the subjects was novel who run a BCI experiment for the first time. He had an excellent IC, but was rather poor during NIC, most probably due to the lack of training. It should be mentioned that the parameterization of the system (decision and rejection thresholds and integration smoothing factor) has been fixed to conventional values for all the subjects.

Discussion and Conclusions

The difficulty of separating specific mental-task related brain patterns in multi-class problems has motivated the use of powerful discriminant classifiers for asynchronous BCI systems. Hence, conventional systems are designed to separate a known number of mental tasks and not to handle arbitrary patterns as those generated during non-intentional control. Encoding such a state as an additional class in the classifier is known to degrade IC performance. However, the presented approach provides the means to achieve a satisfying degree of NIC on top of such a discriminant function, thus not sacrificing robustness and accuracy. Besides the results reported here we have strong evidence in the same subjects, that NIC improves when the subject is engaged in other mental tasks or when he is multitasking, such as speaking with other people. Moreover multitasking did not affect the IC performances. Results with 10 subjects will be reported at the time of the conference.

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B-14 Using Linear Mixed-Effects Models for subject-independent SMR-based BCI classification

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Background and Objective

To reduce preparation times for BCI systems, generally calibration data is recorded and subject-dependent filters and classifiers are estimated. Recently a novel approach, based on a large number of previous experiments, ensemble classifiers and lasso, was able to show that high-performance real-time SMR-based BCI with no calibration time is possible for two class problems [1]. Here we present a novel statistical approach that leads to further improvement on the classification, as well as to interesting insights regarding the neurophysiological and statistical properties of the zero-training BCI framework.

Methods

The original idea of the zero-training BCI was to generate a large number of basis functions (consisting of subject-dependent filters and classifiers) and to reduce them to a small and robust set (by means of L1-penalized linear regression), applicable to any subject. However, this approach falls short of identifying subject-specific effects. Yet, the trials within the training set (approx. 12000) cannot be assumed to be independent: each (training) trial is allocated to one particular subject. Thus, due to this grouping within the observations, we model the data using the mixed-effects model framework [2]. Mixed-effects models are an extension of linear models including effects which are equal for all trials of one subject, but differ between subjects. Our new method thus combines modeling of inter-individual effects with an L1 penalization approach.

Results

By introducing a simple dependence structure to the data, the overall prediction performance can be slightly improved, when comparing our approach to standard machine learning procedures. In contrast to previous methods , our novel model does not simply classify data of unseen subjects, but also gives an insight into the various kinds of variabilities within the data. It shows contra-intuitively that the variability of classifier outputs between the subjects is much smaller than the within-subject variability. The low inter-subject variability is a clear indication that our method is successful in identifying the relevant features and incorporating these into our classification problem.

Discussion and Conclusions

In summary, including the clustering structure into the model is interesting for two reasons: On the one hand prediction accuracy can be improved and on the other hand the between-subject and within-subject variability can be assessed for the first time in a well-controlled statistical framework. Reference: [1] S. Fazli, C. Grozea and M. Danoczy and B. Blankertz and F. Popescu and K.-R. Müller (2009). Subject independent EEG-based BCI decoding. Advances in Neural Information Processing Systems 22 (NIPS), pages 513-521. [2] E. Demidenko (2004). Mixed Models: Theory and Applications, Wiley.

Keywords

Mixed-effects Models, Lasso, zero-training BCI

B-15 BCI Research at EPFL

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BACKGROUND and OBJECTIVE

The Defitech Foundation Chair in Non-Invasive Brain-Machine Interaction carries out research on the direct use of human brain signals to control devices and interact with our environment. In this multidisciplinary research, we are bringing together our previous work on the two fields of BCI and adaptive intelligent robotics. The goal is to develop intelligent brain-actuated devices that people can efficiently operate them in a natural and intuitive manner over long periods of time. Such neuroprosthetic devices will allow interaction by exploiting brain signals associated to different aspects of voluntary behavior.

METHODS

Current EEG-based BCIs are limited by a low information transfer rate and are considered too slow for controlling complex devices. However, we have shown that online asynchronous analysis of spontaneous EEG signals, if used in combination with statistical machine learning techniques and smart interaction designs, is sufficient for humans to do so. Furthermore, thanks to the principle of mutual learning —where the user and the BCI are coupled together and adapt to each other?humans learn to operate the brain-actuated device very rapidly, in a few hours normally split between a few days.

Accordingly, our research is based on the following principles for brain-computer interaction [1]: (1) asynchronous protocols, (2) mutual learning, (3) shared control, where the user conveys high level mental commands that the devices interpret and execute in the most appropriate way to achieve the goal. This is particularly effective for the control of robots and neuroprostheses. Still a fourth principle is to exploit the fact that EEG not only conveys information about the subject's intent (the mental commands), but also about cognitive states that are crucial for a purposeful interaction. All this is done in parallel. An example of such a cognitive state is the user's awareness to errors made by the BCI. Recently we have demonstrated its online use embedded in a BCI, which yields enormous increases in performance [2]. In summary, the last principle is (4) cognitive states. Our approach relies on the extensive use of statistical machine learning techniques at three levels. First, the rapid identification of individual stable discriminant features the user can naturally modulate. Second, the design of powerful statistical classifiers (a Gaussian classifier) to discriminate each EEG sample. Third, the probabilistic smooth integration of the classifier outputs to accumulate evidence about the user's intent. Only when this evidence is high enough, a mental command is delivered to the brain-actuated device. The major point of our framework is the generalization and stability of the selected features to be invariant against fluctuations in the EEG over time.

RESULTS

Over the last years we have developed a wide range of prototypes for mental control (via motor imagery) of a variety of devices: keyboards, games, robots, hand orthoses, and wheelchairs [3]. In addition, we have demonstrated that the recognition of mental states can be successfully used to implement adaptive capabilities in BCI. Most of these devices are relevant for paralyzed humans, but they also open up new possibilities for able-bodied people suffering from "situational disability?such as in space applications —as shown by our recent feasibility study of non-invasive BCI during parabolic flights [4]. In all cases, our framework yields stable long-term performance (several months) and allows subjects to operate different brain-actuated devices, whose control paradigms and associated workloads are quite different, using the same EEG features and classifier. Furthermore, some subjects have demonstrated they can deliver appropriate mental commands only when they wish to do so and while performing other tasks such as speaking.

DISCUSSION and CONCLUSIONS

In summary, we are trying to develop principled methods to design intelligent brain-actuated devices so as to achieve an effective brain-computer interaction and reduce the user's cognitive workload. A recent extension of our framework is the combination of BCIs with existing assistive technologies in order to have a real impact in improving the quality of life of disabled people. In such a hybrid BCI users can merge brain signals with other physiological signals or can switch between different channels naturally (based on monitoring of physiological parameters or mental states). A key element is the design of principled methods for multimodal fusion. ACKNOWLEDGMENTS This work is supported by the European ICT Programme Project FP7-224631 and ICT-2007-225938.

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B-16 The BCI group in LAGIS at Lille University

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Since 2005, when BCI research activities started in our lab -- dealing with classification methods for the P300 Speller [1] -- we have mostly focused our attention on the development of palliative communication interfaces. Like in many labs our BCIs are based on EEG signal analysis, as much from the experimental point of view as from the scientific one. First, we will present the experimental goals of our group in terms of palliation of motor handicap. Then, we will present our scientific contribution to the development of BCI interfaces. These studies have been started thanks to several partners involved in different projects that we will finally clarify. At the experimental level, we essentially explore the domain of self-paced interfaces in which the user is in sole command, unlike in cue-based synchronous interfaces such as P300 Spellers. First of all, we aim at developing a portable system capable of quickly adapting itself to the patient by means of data screening [2]. This system has been used to show the interest and efficiency of slightly invasive interfaces dedicated either to palliative communication or to functional rehabilitation. In this framework, we have experimented a slightly invasive BCI interface on an hemiparetic patient treated for his chronic hand pain by means of an implanted electrode array placed over the dura mater above the sensory-motor area [3]. In order to transfer lab experiments to clinical use, we also aim at defining the most adapted and ergonomic experimental framework for the patients [4]. Besides the experimental approach, based on the background knowledge of our research group [5], we are working on feature extraction in order to discriminate different types of real or imagined movements. We are focusing our attention on fuzzy techniques, aiming at introducing a priori knowledge in the inference system, and in some cases we also use the probability density function underlying the distribution of the data. Thus we design techniques aiming at providing a feedback knowledge to the neurophysiologists by means of interpretable BCI interfaces. We are just starting to work on the use of a reinforcing function (signal) to improve the online learning phase, thus providing a way to measure the communication efficiency between the user and the interface and then to adapt online the classifier coefficients. Our BCI group leans upon local and national collaborations. Indeed, at

Lille, we collaborate with three clinical services of the Hospital Research Center, namely the Neurology and Movement Pathology service (Pr. Blond), the Neurophysiology (Pr. Derambure) and the Functional Rehabilitation (Pr. Thevenon) services. We also work with the human machine interaction team of the Fundamental Computer Science Laboratory at Lille (LIFL). We are involved in two nationwide research groups: the STIC Research Group, where we conduct a specific action aiming at helping different labs to communicate on BCI research by means of national meetings, and the IFRATH group, where we actively collaborate to promote BCIs as technical aids for handicapped people. More recently, we have been involved in a Cooperative Research Action named MABI which will gather for three years the LITIS laboratory of Rouen, the Sequel Team of INRIA Lille, and the TAO team of INRIA Saclay.

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Keywords

motor rehabilitation, slightly invasive BCI, interpretable BCI, fuzzy classification, ergonomy

B-17 Analyzing EEG Data by Multi-scale Tensor Factorization

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Background and Objective

Event related potentials are a commonly used modality for BCI. As a means of feature extraction or outlier detection, one often wishes to decompose ERP data via some form of factor analysis into simpler components, by assuming an underlying multi-linear structure. Components thus obtained are much simpler than the data itself, but are expected to explain them well.

Methods

If the data are given in form of a matrix (e.g., channels x time), several methods are well known to the BCI community, such as ICA or SVD. In our case, the data are given in form of a third-order tensor (channels x time x epochs), thereby enabling us to analyze non-stationarities. The commonly used method for decomposition of such tensors is called parallel factor analysis (PARAFAC) and can be efficiently implemented using an optimization technique known as alternating least squares (ALS). ALS usually performs well on data with little noise. However, with higher noise levels, such as in EEG, it is prone to get stuck in local minima. There exist several approaches in the literature trying to tackle this issue by either imposing smoothing constraints during the minimization or by introducing time shifts into the model. Our approach leaves the ALS as it is. Instead, we view the problem at different smoothing scales. The optimization starts at a very coarse scale, thereby heavily smoothing the data. The previous optimization's output is used to initialize the next, finer scale's optimization. The process is repeated until the desired scale is reached with little or no smoothing. It can be easily shown that smoothing noiseless data results in smooth individual components. With that in mind, our approach can be viewed as imposing smoothness constraints upon the components.

Results

We have applied our method on synthetic data, as well as on real data obtained from experiments in the oddball paradigm. Our results indicate that the novel multi-scale method consistently finds better solutions for the PARAFAC model than the reference ALS algorithm. Moreover, it runs on average about two times faster on synthetic data using the very same implementation of ALS for the individual scales.

Discussion and Conclusions

The advantages of our method are threefold. First, due to its ability to recover multi-linear components with higher fidelity than previous methods , we give researchers a powerful tool for a better understanding and analysis of neurophysiological data. Second, the multi-linear components recovered by our method can be used as a generic improved preprocessing step, e.g. for subsequent BCI classification or decoding approaches. Finally, the higher convergence rate of our multi-scale algorithm enables researchers to use PARAFAC decompositions for on-line settings. Future research will explore tensor structured data with our new method within and beyond the neurosciences.

B-18 EEG Classification using Predictions from Recurrent Neural Networks

Elliott Forney*, Chuck Anderson

Background and Objective

A number of algorithms for the classification of electroencephalogram (EEG) have been proposed in recent years. However, many of these approaches have not yet reached a performance level that is sufficient for practical applications. We hypothesize that a major drawback of current algorithms is their limited ability to incorporate the rich temporal information contained in EEG. This temporal information is often accounted for by embedding a small number of voltages observed from previous time steps into a single input to the classifier. This technique is limited because the temporal information that can be utilized is bounded by the number of embedded values. Furthermore, enough training samples must be observed to sufficiently represent the temporal changes that can take place within this window. We propose that these problems can be overcome with the use of recurrent artificial neural networks (RNN). Since RNN's contain feedback connections, they have an intrinsic state that allows them to generate outputs based not only on the current input, but also based on the sequence of previous inputs.

Methods

EEG is recorded from a subject while they perform a series of imagined mental tasks. A separate RNN is then trained to model the EEG recorded during each mental task by predicting the output of the sequence several steps ahead in time. In this way, we have a set of RNN's that can each be viewed as an expert at predicting EEG similar to that over which it was trained. Classification of previously unencountered EEG can then be performed by applying each RNN and assigning the class associated with the network that was able to model the sequence with the lowest error. We investigate the use of two RNN paradigms: Elman Networks trained using Backpropagation Through Time and Echo State Networks trained using Linear Least Squares. Preliminary

Results

Presently, we have demonstrated that RNN's are capable of predicting an EEG sequence a small number of steps ahead in time with a relatively high degree of accuracy, suggesting that RNN's are able to model EEG well. Preliminary classification results have demonstrated that our approach is able to classify simple artificially generated data with near perfect accuracy. We have also been able to differentiate between eye blink and jaw motion artifacts in EEG. Classification results for EEG recorded during two imagined mental tasks are currently in the 60% range for validation sets and 90% range for training sets when labeling individual time steps. We remain confident that these results will improve with better regularization, preprocessing and a more intelligent decision making process. Further classification studies are in progress and will be presented at the BCI conference.

Discussion and Conclusions

RNN's may provide a mechanism for effectively modeling and classifying EEG. This approach may have the potential to improve upon current algorithms since RNN's may be better able to exploit the temporal information contained in EEG. Improved computational performance during classification may also be offered since the evaluation of RNN's consists primarily of a series of matrix multiplications.

Keywords

Brain-Computer Interface (BCI), Echo State Network (ESN), Elman Recurrent Neural Network, Electroencephalogram (EEG), Recurrent Neural Network (RNN)

B-19 Towards an heuristic-based approach detecting nonstationarities in BCI features

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BACKGROUND AND OBJECTIVE

While allowing for a control of a feedback device via brain activity, Brain-Computer Inter- faces (BCI) still suffer from performance decrements during an online session. As a possible cause for the BCI classification problem, nonstationarities in the statistical properties of the EEG data have been identified. There are numerous studies claiming that new methods of adaptation have to be found (Blankertz et al., 2008, C. Vidaurre et al. 2007, Shenoy et al, 2006) in order to confine the influence of statistical nonstationarities on BCI classification accuracy, but so far no heuristic-based approaches have been developed. Goal of this study was to investigate a cognitive factor possibly influencing nonstationarities: the Loss of Controllability (LoC), thereby enabling the development of a heuristic-based approach.

METHODS

LoC refers to the perceived control the user has over a feedback device. We induced this factor artificially in a highly controlled experimental setup, in a game context. The experimental task was to reach a target by left or right key press. When LoC was introduced, the stimuli behavior did not meet the participant's expectation. For this study 22 healthy participants took part. EEG was recorded at 32 positions. An offline analysis approach (Dornhege et al., 2003) was utilized. Thereby subjects performed a series of clearly defined control actions, while EEG was only recorded and not fed back to the user. An offline analysis was realized by crossvalidation (CV). Features used for classification of left and right hand movements were Slow Cortical Potentials (SCPs) and Event-Related Desynchronization (ERD) features. Feature extractors used were the Common Spatial Patterns for SCP (CSPfSCP) algorithm (Dornhege et al., 2003) and Spectrally Weighted CSP (SpecCSP), as a classifier served Linear Discriminant Analysis (LDA). To assess the impact of LoC on the classifier's performance, pseudo online classification rates (POC) and Kullback- Leibler divergence (KLD) (Shenoy et al., 2007) of the classifier's feature distributions were calculated.

RESULTS

With this study we were able to isolate one cognitive factor responsible for statistical nonstationarities in EEG data: the Loss of Controllablity (LoC). Phases with reduced controllability induced a highly significant deviance of Event Related Desynchronisation (ERD) BCI features but had no significant effects on features from Slow Cortical Potentials (SCP). DISCUSSION AND CONCLUSION Data based online adaptation approaches are lacking an explanation for the causes of statistical nonstationarities. Hence these approaches run the risk of overfitting the adaptation to factors not relevant for the features. By identifying possible causes, like the factor LoC, we follow a new theoretical perspective on a heuristic based approach, applicable to a broader context of settings. Our results also show that statistical nonstationarities in the EEG signal can be traced back to a functional background, and are not random noise. The identified cause for nonstationarities, LoC, could enable the development of new adaptation methods by serving as an indicator for a change in the statistical properties of the EEG data. With this heuristic based approach also other factors could be identified, in order to improve BCI online adaptation.

B-2 A Feature Extraction Method Combining Wavelet Packet Decomposition with Hilbert-Huang Transform for EEG in BCIs

Banghua Yang*, ling yuan, xiaoming zheng, li liu

Background and Objective:

In Brain Computer Interfaces (BCIs), how to continuously distinguish the incoming EEG and so to recognize human's different control intentions is a key problem. The Hilbert-Huang Transform (HHT) consists of the empirical mode decomposition (EMD) and the Hilbert–Huang spectrum (HHS) and it is an adaptive time-frequency analysis method. However, the HHT suffers from some unsolved deficiencies such as: 1) the EMD will generate undesirable Intrinsic Mode Functions (IMFs) at the low-frequency region; 2) the first obtained IMF may cover a too wide frequency range that the property of a mono-component cannot be achieved; 3) the EMD operation can not separate signals that contain low energy components. To eliminate these defects, a method combining the Wavelet Packet Decomposition (WPD) with the HHT is proposed to the feature extraction of EEG.

Methods

Firstly, the EEG signal is decomposed into a set of narrow band signals by the WPD. Secondly, each narrow band signal is decomposed into a set of IMFs by the EMD. And then two kinds of screening process are introduced to select some important IMFs from all IMFs. The first screening process is employed to eliminate some IMFs which have poor correlation with their corresponding narrow band signals. To the retained IMFs, the second screening process is continuously processed to remove some IMFs which are weakly correlated with the original EEG signal. Thus some important IMFs are reserved at last. Finally, the HT is employed on these important IMFs to get the HHS, from which some energy changes in different rhythms can be recognized clearly. The feature vector can be formed from AR model parameters and instantaneous energy (IE) of these important IMFs.

Results

With the dataset of BCI competition IV 2008 Data Set 1, the effectiveness of the proposed algorithm is analyzed and verified from two aspects. One is the HHS and the other is the recognition accuracy. A HHS 3-D figure shows that some energy changes of different states can be observed clearly. The formed feature vector is classified by an optimized support vector machine (SVM). The classification accuracy obtained with the proposed method is higher about 3% than the traditional HHT under the same feature extraction process and classification method.

Discussion and Conclusions

The HHS obtained with the proposed method can not only show obvious energy changes of different states in mu-rhythm, but also show some delicate and regular energy changes in beta-rhythm. Different states can be distinguished via these energy changes. However, The HHS obtained with the traditional HHT method can only show dim energy changes in mu-rhythm. The HHS and the classification accuracy show that the proposed approach can avoid some defects occurred in traditional HHT, which is able to efficiently track energy changes. Evidently it provides a new way for the feature extraction of the EEG signal.

Support

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Keywords

wavelet packet transform (WPT); Hilbert-Huang Transform (HHT); feature extraction; electroencephalogram (EEG); brain-computer interface (BCI)

B-20 Classification of EEG signal for walk intent

Priya Velu*, Paul Hammon, Virginia de Sa

Non-invasive brain computer interface (BCI) applications using electroencephalography (EEG) widely interpret phenomenon such as motor imagery and the visual evoked response for use as commands. Groups including our own have also shown that reach intent can be accurately decoded for general direction of reach to the left or right space. Though motor imagery of the movement of the foot has been studied, the intent to walk has not been explored. We are interested in isolating EEG signals that indicate that a subject intends to walk before any production of gait occurs. Nine subjects were recruited for the study. The task consisted of six conditions: walk left, walk right, walk forward, stand still, point left, and point right. Each trial began with an auditory instruction of one second in duration followed by a silent period lasting one second. Subjects were required to stand still and focus eyes on a fixation cross on the wall for these portions of the trial. A beep sound indicated that the subject could perform the required action, and a second beep sound announced the end of the trial. EEG equipment was securely placed in a backpack with a long fiber optic cable that transmitted data so that subjects could walk while EEG signals were recorded. EOG electrodes were placed to detect eye movements and EMG electrodes were placed on the anterior tibialis muscles of the legs to record the onset of movement. Data were analyzed offline. Standard preprocessing procedures were used. Continuous EEG data was split into epochs centered on the signal to start movement. Epochs were then separated into chunks of 500 ms long staggered at every 125 ms from the start of the epoch. Data were filtered into bands of frequencies (0-3 Hz, 4-7 Hz, 8-13 Hz, 14-25 Hz, 26-40 Hz and 7-30 Hz). Features were extracted using common spatial patterns (CSP), autoregressive modeling (AR), and large Laplacian spatial filtering. Linear discriminant analysis (LDA) was first performed on a training set of data before application to remaining data. We examined the time after the auditory instruction but before the signal to start movement for the intent to walk versus standing. Out of the binary classification of nine subjects, three displayed above chance classification using AR features in the 14-25 Hz band and two in the 8-13 Hz band at the onset of this time period. One subject displayed above chance classification using features derived from CSP in the 14-25 Hz band at the same time point. Preliminary results in which a single subject was instructed to perform motor imagery instead of actual movement show classification rates in the 70-75% range in multiple frequency bands using both features derived from AR and from CSP. This subject did not have classifiable signals for walk intent. Currently we are using meta-classification to combine features from multiple methods for classification by LDA. We will apply the HMM + SVM method developed in our lab. We are also beginning work on an online BCI system that will use signals from walk intent and/or motor imagery. Supported by: #SBE-0542013 NSF Temporal Dynamics Of Learning Center #CBET-0756828 NSF BCI Grant

B-21 A "multi-HMM+SVM" classifier for EEG classification

Eunho Noh*, Adam Koerner , Virginia de Sa

Background and Objective

EEG data is inherently sequential. However most classification algorithms such as LDA and SVM do not use information on the change of brain states over time. HMM classifcation is a standard method used to classify sequential data but selecting precise model parameters is difficult for noisy data such as EEG. Here we propose a classification scheme that exploits the sequential nature of the data but does not require the precise model parameters to be learned. This method also has the benefit of being robust to non-stationary data which is a common issue in EEG-based BCIs(Shenoy, et al. 2009). An analysis of the classifier is done using artificial data. In order to evaluate its performance with EEG data, we use it to classify vowel speech imagery. We compare our results to that of pre-existing classifiers and show the improvement in performance.

Methods

Consider the sequential supervised learning problem with two classes. We want to classify the sequences by modeling each class as an independent HMM. However learning the true model parameters is impossible. We propose a classification scheme using multiple HMM estimations for each class. First, we train the HMMs with different parameters such as number of states and number of emissions. Then we use the Viterbi algorithm to calculate the log likelihood of an input sequence for each HMM estimation. For L HMM estimations, this generates a length L vector of log probabilities which we call the probability vector. Finally, a Gaussian Kernel SVM is used to find a pattern associated with the probability vectors from the same class. We used artificially generated data to show that our scheme is robust to data with non-stationarity between trials. Also a study with off-line BCI data was conducted. The data consisted of EEG data recorded from four subjects performing motor imagery of four vowels, /a/, /i/, /u/, and /ae/. We focused on the pairwise classification of the given vowels for each subject. More specifics of the data set and the experiment is given in "EEG-based classification of context-free vowel production" by Adam Koerner which has also been submitted to this conference.

Results

Analysis with artificial data shows that our algorithm is more robust to non-stationary data than the HMM classifier. The decrease in classification rate from stationary data to non-stationary data is 6.4% compared to that of the HMM classifier which is 8.6%. Also, the classification accuracy of our scheme(81.2%) is significantly higher than the HMM classifier(79.4%) and the SVM classifier(67.2%). The results for the speech imagery classification are also similar. The "HMM+SVM" classifier has the highest classification rates for all subjects where the results ranged between 58~60% with average of 59%.

Conclusion

A hybrid classification scheme combining a mixture of HMMs and SVMs has been proposed. We verified the performance of our classifier using both artificial data and off-line BCI data. It would be meaningful to analyze the performance of this classifier as we increase the length of the input sequence.

B-22 A Comparison of Univariate, Multivariate, Bilinear Autoregressive, and Bandpower Features for Brain-Computer Interfaces

Clemens Brunner*, Martin Billinger, Christa Neuper

Background and Objective

The signal processing toolchain in a brain-computer interface (BCI) consists of several components that influence the overall performance of the system. In general, raw electroencephalographic (EEG) signals are first preprocessed with temporal or spatial filters. Next, features are extracted before the final classification stage. After that, a control signal can be derived. The aim of this offline analysis was to assess the influence of different feature types on the overall performance of a BCI measured by classification accuracy. Specifically, these feature types were: univariate autoregressive (AR) parameters, multivariate AR (MVAR) parameters, bilinear AR (BLAR) parameters, and logarithmic band power (BP) features.

Methods

We used data set 2A from the BCI Competition 2008. Nine subjects took part in two sessions on different days. The cue-based paradigm involved four different motor imagery tasks (left hand, right hand, foot, tongue). A session consisted of 6 runs with 48 trials each (12 for each of the four classes). We used signals from three bipolar electrodes, C3, Cz, and C4. From those three EEG channels, we extracted different features: (1) univariate AR parameters for each channel, (2) multivariate AR parameters for all three channels, (3) bilinear AR parameters, and (4) logarithmic BP features. We hypothesized that MVAR and BLAR parameters could yield higher classification accuracies because they contain more information about the underlying signals. In contrast to univariate AR parameters, MVAR parameters also describe the relationships between the single channels and BLAR parameters can model certain non-linear signals. We first determined the optimal parameters (model order and update coefficient) for the three different AR models with an exhaustive grid search. We optimized the frequency bands for the BP features with a feature selection algorithm. For this optimization stage, we used only the data from the first session. We optimized parameters individually for each subject as well as globally over all subjects. The optimization criterion was to maximize classification accuracy. We also used BP with default bands (10-12Hz and 16-24Hz) for comparison. We evaluated the performance using the optimized parameters on the second session by calculating classification accuracy using a 10x10 cross-validation procedure.

Results

We found no significant differences between the different feature types. MVAR parameters and BLAR parameters could not exploit their theoretical advantages over the univariate AR model. Moreover, the frequently used BP features did not differ significantly from the AR methods . Surprisingly, there was also no difference between parameters optimized for each individual subject and globally optimized (or default) parameters.

Discussion and Conclusions

In conclusion, we reported the following two findings. First, there is no significant difference between AR and BP features. This occurred because both methods describe the spectrum of the signals, and therefore result in similar BCI performance. Second, optimizing parameters individually for each subject is not necessary; using default parameters yielded equally high results .

B-23 Rapid EEG-based BCI Setup with an Intelligent Multistage Signal Processing Framework for Accurate Online Communication and Control

Damien Coyle*, Abdul Satti, t. Martin McGinnity

Background and Objective

The major focus of BCI research at the Intelligent Systems Research Centre, University of Ulster is on the development of a combination of signal processing tools to tackle the main challenges in continuous control protocols for motor imagery based synchronous and self-paced BCIs. This work will outline progress in the development of a multistage signal processing framework which can be setup rapidly and automatically even when conducting a global search for subject-specific parameters. A range of offline results and online analysis of a newly developed game illustrate the potential for the proposed BCI.

Methods

The BCI includes a prediction based preprocessing framework, referred to as Neural-Time-Series-Prediction-Preprocessing (NTSPP), which permits multiple-step-ahead prediction of the EEG time-series, where different prediction networks are trained to specialize in predicting future samples of different EEG signals. Due to network specialization on specific motor imagery tasks and EEG channels, features extracted from the predicted signals are more separable and thus easier to classify. NTSPP adapts to each subject autonomously using self-organizing fuzzy neural networks (SOFNN). Recently, NTSPP has been combined with the popular Common Spatial Patterns (CSP) approach which maximizes the ratio of class-conditional variances of EEG sources. Combining NTSPP with CSP along with spectral filtering (NTSPP-SF-CSP) has shown significant potential for two-class and multiclass BCIs involving hand, foot and tongue motor imagery classification. Prior to performing these signal processing stages, data dependent parameters are selected because when dealing with multichannel data where classification accuracy is maximized by selecting subject-specific frequency bands and training the classifier on the time point of maximum separability, which is normal for motor imagery BCIs, the parameter search space can be extensive. A robust approach has been developed to efficiently find the global optimum of this space using Particle Swarm Optimization (PSO) along with a frequency based correlation analysis, where an inner-outer cross-validation(CV) is performed using the Matlab?Parallel Processing Toolbox, enabling rapid BCI setup. This combination of techniques results in an accurate BCI however there are other issues for online BCI deployment which we have addressed using a novel postprocessing module that accounts for class bias behavior and improves feedback stability through Savitzky-Golay smoothing.

Results

Offline results show that the NTSPP-SF-CSP preprocessing framework significantly outperforms either approach operating independently and produces good performance even with a low number of EEG channels. Elements of the BCI presented here ranked well on Datasets 1, 2a, and 2b in the recent International BCI Competition IV. The difference in performance of the top 4 placed submissions for Dataset 2b were not statistically significant even though the methods presented here use a 1s window compared to the 2s window employed by the other contestants. Longer windows introduce latency in the online feedback and the advantage of a shorter window can be demonstrated where the user is required to quickly and continuously manipulate the position of a game object. Discussion and Conclusion A BCI which can be adapted quickly and easily to each individual with the capacity to provide accurate, stable and low latency feedback has been developed. Online trials with healthy subjects are ongoing and funding has been obtained for trials at the National Rehabilitation Hospital of Ireland.

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Keywords

(maximum of 6) EEG-based BCI, motor imagery, time-series prediction, preprocessing, post-processing, BCI-games

B-24 Subject-Specific Data-Segment-Related Parameters for Improvement of EEG Signal Classification in Brain-Computer Interface

Walter Besio*, Hongbao Cao, Xiang Liu

Background and Objective

In electroencephalography (EEG) modeling techniques, data segment selection is the first and still an important step. Due to subject specificity, not all data recorded is suitable for constructing the model. The objective

of our work was to analyze the influence of a set of data-segment-related parameters on feature extraction and classification in an electroencephalogram (EEG)-based brain–computer interface (BCI).

Methods

Left/right hand cued motor imagery EEG was analyzed by an autoregressive (AR) model for feature extraction, and Mahalanobis distance based linear classifier for classification. Then an auto search algorithm was used to study four data-segment-related parameters in each trial of twelve subject's EEG. The parameters were: 1) the length of data segment (LDS), 2) the start position of data segment (SPD), 3) AR order, and 4) number of trials (NT) used to build the model.

Results

The study showed that, compared to the classification ratio (CR) without parameter selection, the CR was significantly different with an increase by 20% to 30% with proper selection of these data-segment-related parameter values, and that the optimum parameter values were subject-dependent.

Discussion and Conclusion

This suggests that the data-segment-related parameters should be individualized when building models for BCI.

B-3 Conditional Random Fields as Classifiers for 3-Class Motor-Imagery Based BCIs

Bashar Awwad Shiekh Hasan*, John Gan

Keywords: Conditional Random Fields, Hidden Markov Models,BCI.

Background and Objective

This paper proposes a novel method to classify motor-imagery tasks in a synchronous BCI setting. The method proposed uses Conditional Random Fields (CRF) to build a discriminative model of the temporal properties of the EEG trials. The method is tested on three subjects with three motor-imagery tasks. The results show enhancement over Hidden Markov Models (HMM). The advantages of this model over HMM are both theoretical and practical. Theoretically CRF focuses on modelling the latent variables (labels) rather than modelling both the observation and the latent variables. This is translated by not explicitly modelling the marginal probability P(X) where X is the observed variable. CRF also overcomes the label bias problem [1]. Furthermore, its loss function is convex, guaranteeing convergence to the global optimum. Practically and for the previous theoretical reasons, CRF is much less prune to singularity problems allowing the use of both frequency and time features (such as band power), HMM on the other hand requires time features (such as autoregressive).

Methods

EEG data were recorded from three healthy subjects, with five bipolar channels. In each trial of eight seconds, the subjects were asked to perform one of three motor imagery tasks (right hand, left hand and right foot movements). Bandpower features were extracted and Sequential Floating Forward Search (SFFS) method was used to select the most separable features. Let X be a random variable over data sequences to be labelled, and Y is a random variable over corresponding label sequences. By definition, CRF is a random field globally conditioned on the observation X. This random field is represented by an undirected graphical model G. The vertexes in the graph are the labels Y. In a CRF, the distribution of each discrete random variable Y is conditioned on an input sequence X. The edges in G can in general take any configuration. To simplify the model, the vertexes are assumed to be only linearly connected. X as well is assumed to have a sequence structure, although this is not necessary in general. A quasi-Newton method [2] is used here to maximize the log-likelihood of the objective function. A 3-label CRF model was used, each label corresponding to one motor-imagery task. The trials are considered to be one chain and the model is trained by providing the trials as independent training samples. To classify a new sample the likelihood of every label giving sample data is calculated. The label with the highest likelihood is considered the classification result.

Results and Discussion

Table 1 presents the end-of-trial results using the mentioned methods . A 4-fold cross-validation method is applied to get the results for HMM and CRF. Result on more subjects and more analysis will be provided in the full paper. CRF as presented here offers a discriminative alternative to HMM. The initial results show that CRF outperforms HMM. Better classification and post-processing methods are necessary to enhance the accuracy. CRFs are a branch of a more general family of graphical models, Markov Random Fields (MRF). MRF in general is able to model spatial relationships between different random variables, which could have the potential of building more sophisticated models that can model both temporal and spatial properties of EEG data. The future work will focus on applying CRF on asynchronous BCI data and to build MRF-based models for EEG data. Subject CRF% HMM% a 74.17 65.67 b 49.17 58.33 c 61.67 36.25 Table 1: CRF and HMM results

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B-4 Improved Feature Set for Mental Task EEG Based BCI

Tugce Balli*, Ramaswamy Palaniappan

The traditional feature extraction methods for characterisation of EEG signals, especially in Brain Computer-Interface (BCI) designs, are mostly dependent on time-frequency based methods . Therefore, there is little to no literature on the use of nonlinear features on the characterisation of EEG signals for mental task classification. In this study we set out to investigate the characterisation ability of three conventional linear features namely the band power (BP), autoregressive (AR) model coefficients, AR reflection coefficients and a nonlinear complexity measure namely the approximate entropy (APEN) for classification of multi-channel electroencephalogram (EEG). Furthermore we propose to combine these features in order to improve the classification accuracy of EEG signals which were recorded during motor imagery and cognitive tasks. The EEG data used in this study is the Data set V of BCI Competition III. In this data set, the EEG signals were recorded from three subjects, during imaginary left hand movement, imaginary right hand movement and imaginary word generation starting with same random letter. For testing the separability of features, initially the raw EEG data was high-pass filtered with a cut-off frequency of 0.5Hz and pre-processed with common average referencing. Next, the signals were band pass filtered using eight distinct frequency bands corresponding to delta (0.1-5Hz), theta (5-8Hz), alpha (8-12Hz), sigma (12-15Hz), beta (15-25Hz) bands along with three gamma bands (25-35, 35-45, 45-55 Hz). Finally the data from each frequency band has been spatially filtered using common spatial patterns (CSP) method. Features were estimated from spatially filtered EEG segments. Class separability of individual features was investigated using linear discriminant analysis (LDA) method. The combined feature sets were created by using sequential floating forward search algorithm with LDA classifier (SFFS-LDA) where a subset of 15 features were selected from the feature space. The results have demonstrated that, based on the comparison among features, band power feature provided the highest classification accuracies of 80.02%, 62.07% and 61.65% for subjects 1, 2 and 3 respectively. Combining linear features and nonlinear complexity measure demonstrated a significant improvement in the classification accuracy for all of the subjects where an accuracy of 86.96%, 84.35% and 85.16% was obtained for subjects 1, 2 and 3. These findings demonstrate that the linear and nonlinear features are complimentary to each other where these features represent distinct properties of EEG signals. Hence the linear and nonlinear features provide an enhanced representation and class discrimination when used in combination. Keywords: Electroencephalogram, Common Spatial Patterns, Band Power, Autoregressive Model, Approximate Entropy

B-5 Asynchronous Mind-reading Based on EEG Source Imaging

Han-Jeong Hwang, Chang-Hwan Im*

Background and Objective:

The aim of our study was to classify various cognitive tasks designed to elicit different brain responses without a cue. We proposed a new analysis method based on EEG-based real-time cortical source imaging which the authors introduced recently.

Methods

Using the real-time dynamic neuroimaging system, we could construct 2-dimensional pattern maps consisting of event-related (de)synchronization (ERD/S) values evaluated at different regions of interest (ROIs) on the cortical surface and various frequency bands. After constructing a database for each of different mental tasks, we applied a real-time classification process to read the individual's intentions. Two healthy participants took part in this study and EEG data were recorded during the experiment with 32 electrodes mounted on their scalp according to the extended international 10-20 system. We asked them to carry out eight different mental imagery tasks corresponding to the instructions displayed on a monitor in front of them. After the 2D pattern maps were constructed, a cross correlation analysis was applied to all datasets to select distinct tasks which have high intra-class correlation and low inter-class correlation. We applied a unique fitness evaluation technique for the real-time classification.

Results

As a result, we could classify four different mental tasks with 90% classification accuracy from one participant and six mental tasks with 88.5% classification accuracy from the other participant.

Discussion and Conclusions

These preliminary results suggest that various cognitive tasks can be discriminated noninvasively and asynchronously with high precision, using our method. It is expected that our mind-reading system can be used to help locked-in patients communicate with others. Keywords: Mind-reading, EEG source imaging, asynchronous BCI

B-6 Classifying EEG using Incremental Support Vector Machine in BCIs

Xiaoming Zheng*, Banghua Yang, Ling Yuan

The discrimination of movement imagery event-related electroencephalography (EEG) is an essential issue in brain-computer interfaces (BCIs). Classifying EEG signals is an important step in the discrimination. From the physiological standpoint, EEG signal varies with the time elapse, mood, tiredness of the subject, etc. An on-line BCI should be adaptive to tackle the dynamic variations of EEG. One of the solutions is to have the classifier's parameters adjustable while the system is used online. In this paper, an incremental support vector machine (ISVM) is adopted to classifying the EEG. The ISVM can consecutively delete some history samples and replenish some new samples obtained lately. And so the classifier model of the ISVM is updated periodically to adapt to the variations of EEG. At the same time, the ISVM can use a small training set to train the classifier, which is better in training speed, memory consuming than standard SVM. To the data set 1 on left hand and foot imagery of BCI Competition IV 2008, in this paper, empirical mode decomposition (EMD) is employed to decompose the EEG signal into a series of intrinsic mode functions (IMFs), and then AR model parameters and instantaneous energy (IE) can be gained from some important IMFs, which form the initial features. The extracted features are fed into the ISVM classifier. Compared with the standard SVM, elementary results show that the ISVM can obtain better classification performance. The ISVM provides a good way to solve the adaptability of the online BCI system. The effectiveness of the ISVM should be verified furthermore with more data and subjects.

Support

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Keywords

incremental support vector machine (ISVM); electroencephalogram (EEG); brain-computer interface (BCI); empirical mode decomposition (EMD)

B-7 A Bispectrum based feature extraction technique for devising a practical Brain-Computer Interfacing system

Shahjahan Shahid*, Rakesh Sinha, Girijesh Prasad

Keywords: motor imagery, bispectrum, LDA, Cohen’s Kappa.

Background and Objective

One of the major challenges in EEG-based motor imagery (MI) BCI is to extract distinctly separable features from non-stationary brainwaves during online operation. Currently most existing feature extraction (FE) schemes are based on common spatial pattern (CSP), auto-regressive (AR) models or power spectral density (PSD) approaches. These methods however make certain limiting assumptions regarding EEG signals e.g., they have Gaussian distribution and uncorrelated frequency components. Considering these limitations, the objective of this work was to investigate simple higher order statistics (HOS) features that do not involve the Gaussianity assumption. To assess how robust and invariant these features are, it was aimed to evaluate BCI performance on multiple subjects undergoing trials over multiple sessions. To this end, we have developed an off-line BCI system comprising of a bispectrum based feature extraction procedure and a linear discriminate analysis (LDA) classifier. Our BCI system has been tested with BCI Competition IV dataset-2b and it outperforms the winner of that competition.

Method

The BCI system works in two stages: training stage and application or evaluation stage. In training stage, the BCI system uses the FE followed by a cross-validation subsystem and finds best parameters for the FE subsystem. With suitable parameters for FE, the system finds the optimal coefficients for LDA classification. In evaluation stage, it uses the best found FE parameters and the LDA coefficient. FE Technique ?Bispectrum of any random signal provides supplementary information to the power spectrum of that signal. Bispectrum of an additive statistically independent multi-source signal is the sum of their individual bispectrums. In addition, its value is theoretically zero, if random signal is Gaussian or independent, identically distributed (i.i.d.). A bispectrum of EEG signal Bx can be computed from Bx(k,l)=X(k)X(l)X* (k+l), where X(?= FFT[x(t)]; x(t) [t=1,2,..,n] is EEG signal; X*(? is the complex conjugate term of X(?; and k, l are the frequency indices. Since any system noise is generally assumed as Gaussian and/or i.i.d. signal, the Bx is free from its effect. Note that, for the BCI system development, the EEG signal x(t) is to be band-pass filtered. In order to characterize temporal spectral information, we compute the sum of absolute log-bispectrum as B(m)=Sum[abs(log[Bx(k,l)])], where m is a time index related with the time period from which bispectrum is estimated. We use 2 s long EEG with 0.1 s step size. Estimation of optimal parameters and LDA coefficients ?To get optimal parameters for FE, we trained the BCI system and found maximum possible separablity by the LDA classifier. We performed five-fold cross validation accounting all subjects?training dataset at different frequency bands vs. various sizes of EEG data (m). We chose those parameters for FE for which the average accuracy becomes highest. Finally, the system uses the best FE parameters and finds the optimal coefficients for the LDA classifier.

Results

BCI competition IV data-2b (provided by Graz BCI team, see http://www.bbci.de/competition/iv/desc_2b.pdf) has been used for the study. The system was trained on the 3rd session of each subject and evaluated on 4th and 5th sessions (i.e. sessions with feedback). We use EEG from C3 and C4 channels only. From cross validation stage, it is found that the overall best accuracy can be achieved for all the subjects with a common set of the mu-band (8-14Hz) and the beta-band (14-27Hz) features from each of the EEG signals. With optimal parameters, we evaluated our system for maximum accuracy and Cohen's kappa coefficient. The subject-wise kappa coefficients obtained from the evaluation stage were 0.43, 0.38, 0.20, 0.95, 0.59, 0.68, 0.56, 0.90, and 0.75. The average accuracy at training stage was 82% (with 83% left & 81% right MI) and at evaluation stage was

80% (with with 84% left & 76% right MI). Additionally, compared to a PSD based FE method, this method always provided higher and stable kappa value right across the MI period.

Discussion and Conclusion

The FE method has provided promising average kappa value of 0.605 over the evaluation datasets which is higher than that of the competition winner (0.60). The results showed balanced accuracy for left and right MI on each subject. The average kappa, mutual information and accuracy in training and evaluation stages were also very close. It is worth noting that higher kappa values may be achieved with subject-specific frequency bands and LDA parameters. Based on the promising results , it can be concluded that the bispectrum based FE technique has the ability to extract robust and much less variant features from EEG signals which may not be possible with traditional covariance or PSD based techniques.

B-8 CSP Patches ?an Optimized Filter Ensemble for Adaptive BCI Systems

Claudia Sannelli*, Carmen Vidaurre, Klaus-Robert Müller, Benjamin Blankertz

BACKGROUND AND OBJECTIVES

Laplacian filters are commonly used in Brain-Computer Interfacing (BCI). Band power calculated on few Laplacian channels in a broad or subject specific frequency band represents an easy and general feature to control a BCI [McFarland1997]. Spatial filters that are subject specifically optimized by Common Spatial Patterns (CSP) analysis lead typically to an improved performance [Blankertz2008], but have the drawback that they require a considerable amount of training data and are not suitable for adaptation. Therefore, Laplacian filtering is preferred to CSP, e.g., in the initial period of "co-adaptive calibration" [Vidaurre2009]. Here, the use of an ensemble of local "CSP patches" is proposed, which can be considered as a compromise between Laplacian and CSP. The method can be used already when few channels and trials are available and is suitable for online adaptation, but offers the classification capacity of CSP.

METHODS

A Laplacian derivation for one channel, results from the subtraction with equal weights of the activity of the surrounding channels from the activity of the channel itself. The filter proposed here is, instead, the linear derivation of the surrounding channels plus the central one, where the weights are determined by CSP analysis of the few trials and channels available. The resulting features are an ensemble of "CSP patches": instead of n Laplacian channels, nx2 CSP features are obtained, since in training the CSP one filter per class is automatically chosen [Blankertz2008]. For evaluation eighty data sets recorded during a classical motor imagery BCI paradigm are used, with a calibration session with 150 trials and a feedback session of 300 trials. The performance on the feedback data of Laplacian channels C3, Cz and C4 is compared with the corresponding CSP patches. In particular, both methods are trained on an increasing number of training trials starting from ten. Several patches are considered, from the "small" one with four surrounding channels (requiring then 13 channels in total), to a large one with 22 surrounding channels (requiring then 51 channels).

RESULTS

The CSP patches outperform the Laplacian channels in all configurations. While the test error of Laplacian channels decreases with the number of surrounding channels, reaching for example with 40 training trials an error of 26.6% with the largest patch, the CSP patches with three small patches on C3, Cz and C4 exhibit with 40 training trials already an error of 24.4%. The comparison results are very similar if considering a broad frequency band or a subject specific one.

DISCUSSION AND CONCLUSIONS

The CSP patches approach performs significantly better than the normal Laplacian channels. In contrast to conventional CSP-based approaches, the CSP patches can be used in combination with an adaptive classifier to account for the changes in brain patterns during a co-adaptive calibration [Vidaurre2009].

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KEYWORDS

Brain-Computer Interfacing (BCI); Co-adaptive Learning; Common Spatial Patterns (CSP); Electroencephalogram (EEG); Laplacian Derivation; Spatial Filtering.

B-9 Variability in Subjects Supports Optimization of Signal Feature Extraction and Classification

Mark Renfrew*, Janis Daly, Kenneth Hrovat, Cenk Çavusoglu

Background and Objective

Current rehabilitation methods often fail to restore normal brain function and motor control after stroke. Brain-computer interfaces (BCI) have been used for device control for paralyzed individuals, but BCIs have not been widely investigated for motor retraining after stroke. The objective of this study was to investigate the usefulness of several brain signal feature extraction (FE) and classification methods for an EEG-based BCI system.

Methods

We collected electroencephalographic (EEG) signals during the performance of a wrist/finger motor task performed by four control subjects and three subjects with persistent motor deficiencies after stroke (>6mos). EEG data were collected using a 58-channel ECI ElectroCap EEG cap and Compumedics Neuroscan software and amplifiers. The electrode locations on the cap conformed to the International 10-20 standard and all electrodes were referenced to ground electrodes placed on the subject's earlobes. All electrode-scalp impedances were reduced to 5 kO or less through the use of an electrically conductive saline gel and the impedance-measurement capability provided by Neuroscan Acquire software. EEG data were sampled and digitized by Neuroscan Acquire, with a gain of 500 and a sampling rate of 250 Hz, and bandpass filtered from 0.1 - 40 Hz. We tested three FE methods : 1) autoregressive filtering (AR), 2) mu-matched filtering, and 3) wavelet decomposition (WD). In addition, we tested two classification methods : 1) support vector machines (SVM) and 2) linear classifiers with a manually-determined weight vector. Signal classification was conducted on the extracted features using MATLAB. For each of six feature extraction methods , three classifiers were tested: 1) an implementation of the BCI2000 linear classifier, in which classifier weights were set manually after examination of the subjects?EEG signal, 2) a Support Vector Machine (SVM) using data from the same channels used by the clinical classifier, and 3) an SVM using data from these electrodes: C3, C1, CZ, CP3, CP1, and CPZ for right-handed subjects; channels C4, C2, CZ, CP4, CP2, and CPZ for left-handed subjects. The accuracy of the predictions produced by each method was then compared. Each combination of classification and feature extraction methods was statistically compared to all others using Student's t-test.

Results

No difference was found between linear and nonlinear SVMs. Biorthogonal wavelets were found to perform poorly. The highest classification accuracies were produced by SVMs trained on data from the subject's motor channels and using 2nd order (Stroke subject 1) or 8th order Daubechies wavelets (Control subjects 2 and 4). Statistically significant greater ($p < 0.05$) classification accuracy versus baseline method (AR feature extraction with the clinical classifier) was found for three of seven subjects: control subjects 2 and 4, and stroke subject 1. Three of the remaining subjects showed a trend that did not reach significance ($p < 0.05$). The final subject showed no difference in classification accuracies for tested methods versus the standard method. For one control and one stroke subject, there was a statistically significant ($p < 0.05$) greater classification accuracy, using WD FE and linear classification, versus the baseline method of AR FE and linear classification. Discussion and Conclusion

Results

showed high variability across subjects in response to different feature extraction and classification methods . For many stroke survivors, it may prove difficult to control the brain signal for BCI use. The results of this investigation suggest that some optimization of the brain signal FE and classification methods might provide the needed edge to stroke survivors with impaired brain signal who may have difficulty gaining control of a BCI at initial sessions.

C-1 Pyff--A Platform-Independent Open-Source Feedback Framework for BCI Systems

Bastian Venthur*, Benjamin Blankertz

Pyff--A Platform-Independent Open-Source Feedback Framework for BCI Systems Bastian Venthur, Benjamin Blankertz Machine Learning Laboratory, Berlin Institute of Technology, Germany

Background and Objective

Pyff is a platform independent, open source framework for the development of BCI stimulus and feed-back applications in Python. The motivation for this framework is to make the development of those applications as easy and fast as possible. We chose Python because is easy to learn even for inexperienced programmers and provides many bindings to external libraries for high quality graphics and sound. Thus, Pyff provides a good compromise between flexibility and high performance on one side and small programming effort for applications on the other. Pyff is written for, but not limited to BCI applications. Due it's generic nature, it is also suited for arbitrary psychophysical experiments. We believe that a standard platform for BCI feedback application will foster a vivid exchange of applications between different BCI groups. Furthermore, it allows an easy reproducibility of psychophysical experiments, if authors provide the code of their stimulus presentation.

Methods

The framework consists of four major parts: the Feedback Controller, the GUI, a collection of Feedback baseclasses and a set of ready to use Feedbacks. (Note that in Pyff's terminology a Feedback is an application controlled by the Feedback Controller. A Feedback can be a full BCI feedback or just a stimulus presentation.) The Feedback Controller takes care of the communication between the Feedback and the rest of the BCI system. The GUI is a remote control for the Feedback Controller and the Feedback. Within the GUI it's also possible to inspect and manipulate parameters of a Feedback (like size, position and color of visual objects) on the fly which is very useful to explore different configurations for an experimental paradigm. The Feedback baseclasses are a set of specialized baseclasses, each of them implementing a set of useful methods for a special purpose. For example, the PygameFeedback baseclass implements some common methods each feedback needs when utilizing the module Pygame. The framework is loosely coupled with the rest of the BCI system, thus it should run with most existing BCI systems with very few modifications. The loose coupling is achieved through the communication via network and a simple XML Data format.

Results

Our group uses this framework successfully as primary platform for feedback development. Experience with Pyff in lectures showed that students, even the ones with little Python experience, can implement a decent Feedback within a few days. Furthermore, PyFF is already used by various partners of the large European BCI consortium Tool for Brain-Computer Interaction (TOBI).

Discussion and Conclusions

The Pythonic Feedback Framework provides a solution for writing high quality BCI feedback applications with minimal effort. Through the use of a standardized interface using a standard protocol for the communication with the BCI system, this framework is very generic and it should be easily adaptable to most existing BCI systems. Moreover such a unified feedback framework creates the unique opportunity of exchanging BCI feedback applications between BCI groups, even if individual systems are used for processing and classification. The presented framework runs on every major platform (Linux, Mac and Windows), is Free Software and licensed under the terms of the GNU General Public License (GPL). The Homepage of the project is: http://www.bbci.de/pyff. Keywords: BCI, Software, Open Source, Python

C-2 BrainStream: a MATLAB environment for definition and execution of Brain Computer Interfaces

Philip Van den Broek*, Rutger Vlek, Peter Desain

Background and objective

For the execution of BCI experiments, researchers can choose from available software like BCI2000 or OpenViBE, which are well suited for the most common BCI paradigms. However, when research concerns a new BCI approach, researchers need to develop custom applications in programming languages such as C or C++. When required programming skills are restricted to a user-friendly language, like MATLAB, many more researchers can contribute to development of BCI systems. BrainStream opens up this opportunity by providing an open-source, MATLAB-based environment for definition and execution of BCI experiments.

Methods

Key concept of the design is that incoming markers in the data stream dynamically determine the actions of the system. Users can predefine a user variable space and a variety of actions for incoming markers, such as the enrichment of a marker as event: adding annotations and brain data, a modification of a variable or the execution of a MATLAB function. There are different options to specify the exact timing of execution of these actions: instantaneous, at a fixed delay, relative to another marker, or when a specified piece of data is available. In runtime, BrainStream maintains the variable space, which allows for easy access to the experiment‘s current state from user functions, as well as exchange of information between sub parts of the experiment. The explicit nature of the action definitions and the experiment state monitoring allows for automated allocation of computation for parallel execution (on multi-core or multi-machine) increasing the amount of computational power. BrainStream experiments are defined in a tabular structure, where actions are defined for each possible marker along with the timing information. A hierarchical architecture is implemented for the interpretation of these tables, allowing for modularity and inheritance of generic functionality into a specific experimental design. Any device providing means to stream data can be used with BrainStream; currently the integration with the Fieldtrip real-time buffer already handles support for couple of hardware devices (including streaming data from BCI2000). Stimulus presentation can be programmed within BrainStream or be handled by packages like PsychToolbox, presentation or various media players. Future developments will focus on support for brain signals other than EEG, handling simultaneous acquisition of different type of brain signals, and specific equipment used in animal research. More information is already available at the website: www.brainstream.nu.

Results

Motor imagery, P300 speller and music brain reading BCI experiments as well as try-outs of new BCI approaches have been successfully defined and executed using BrainStream. Student users can start building their experiments with little prior experience.

Discussion and Conclusions

The completely dynamic yet explicit approach to definition of BCI experiments distinguishes BrainStream from other available software environments for BCI. BrainStream integrates well with popular MATLAB-based analysis toolboxes, such as Fieldtrip and EEGLab, and together with its modular approach to experimental design, it allows for rapid compositions of new BCI-experiments and easy exchange of experiments - irrespective of utilized hardware and operating system ?among institutes. This makes BrainStream especially attractive to the scientific community.

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Keywords

brain-computer-interface (BCI), electro-encephalography (EEG)

Support

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C-3 MatRiver software for real-time analysis and visualization of EEG and multi-modal data

Nima Bigdely Shamlo*, Andre Vankov, Scott Makeig

Background and Objective

Most current BCI systems rely on compiled code (usually C++) for real-time operations. Although this has the advantage of faster computation, it limits the flexibility of the system and increases the time needed to implement new features. Recent performance gains in computer hardware and the introduction of multi-core CPUs have made it possible to process data in real-time using the Matlab scripting language and processing environment. Here we introduce a new software package, called MatRiver [1], which is a set of Matlab functions optimized for real-time data processing, buffering and visualization with emphasis on EEG analysis.

Methods

MatRiver operates in conjunction with the data acquisition, distribution and synchronization system developed by A. Vankov, called DataRiver [2]. With DataRiver, input data is buffered on the local machine outside Matlab and MatRiver system does not have to continuously check for newly arrived data. MatRiver can check the buffer on regular (0.1 s or less) intervals by exploiting timer objects and read all the newly arrived samples in one quick step. This feature is essential for real-time operations since it eliminates the chance of sample loss when Matlab process is busy. MatRiver provides a pipe-line for EEG pre-processiong and classification. In addition to performing common EEG processing steps, such as channel selection, re-referencing, frequency filtering and linear spatial filtering (ICA [3][4][5] or other models), MatRiver includes simple-to-use routines for dynamic noisy ‘bad?channel detection and compensation (based on ICA source model [6]). The pre-processed activity of channels or independent components is accumulated in Matlab and may be used for event-based classification or continuous visualizations of derived EEG features, such as Alpha-band power. MatRiver functions are usually invoked by timer objects in specified intervals which frees up the CPU time between these runs. In addition, Event-based EEG classification is facilitated by using Matlab callback functions that are executed at predefined latencies after selected events (triggers). This architecture allows for use of any classifier function accessible in Matlab.

Results

As MatRiver is optimized for speed of computation and display, EEG preprocessing and most event-based classifications can be performed in less than 10 ms on common hardware. Also, continuous visualizations of derived EEG features (such as Alpha power) may rendered at more than 19 frames per second. In the gaming industry, response latencies must be less than 80 ms for the subject to consider the system reaction to be real time. MatRiver can achieve comparable or better response latency in most applications that involve continuous visualizations.

Discussion and Conclusions

With MatRiver, users can leverage their existing knowledge of Matlab and its extensive mathematical and visualization capabilities. Existing Matlab scripts for EEG analysis and classification can be easily used in conjunction with MatRiver functions with minimal modifications. This greatly reduces the need for re-implementing the same code in different languages for real-time implementation (e.g., from original Matlab code used in offline analysis to real-time C code). This ease of use may allow easier exploratory development of more complex and powerful real-time analysis methods .

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Support

Office of Naval Research, The Swartz Foundation

Keywords

BCI, EEG, Brain-Computer interface, HCI, Realtime, Matlab

C-4 Bristlesensors ?Soft, Flexible Dry EEG Electrodes for Neurofeedback and BCI Applications

Cristian Grozea*, Catalin Voinescu

[A pdf version of this abstract, which includes the figure is at http://www.brainsignals.de/users/cristian.grozea/articles/bristlesensorbci2010shortened.pdf]

Background and Objective

Dry EEG sensors are important for BCI technologies to gain wide-spread long-term use. The gel-based ones present inconveniences: gel is wet, it dries up and itches, requires hair washing afterwards, varying impedances and need for periodical recalibration. The existing dry EEG electrodes (typically arrays of metallic pins) have higher impedances than the wet ones, dependent on the level of pressure, and thus stable in time. This pressure makes them “bearable?to some (as opposed to “comfortable?. Quoting one early designer and user of such pin arrays, “the thin pin arrays can hurt your skin if you use them (for) too long?[1]. Here a new dry EEG electrode is proposed, able to outperform electrically the existing dry electrodes while reducing the discomfort by distributing more uniformly and more flexibly the pressure on the skin of the scalp through the hair. The novelty consists in using conductive bristles instead of pins. Figure 1. (a) prototype 2; (b) Spectrum (log-amplitude for 2 to 45 Hz); (c) N100 AEP

Methods

The prototype1 uses metallic bristles from a soft wire brush. Its test consisted in contrasting the spectrum of the occipital signal (at Oz) recorded when 5 healthy male subjects had the eyes closed vs. eyes open (30s each) - using a wet reference electrode. The prototype2 (Fig.1a) is softer than the first one, as it has been obtained by coating thin polymer bristles with silver particles. With this prototype two paradigms have been tested on three healthy male subjects: (Fig.1c) the N100 auditory evoked potential, using the procedure described in [2,3], and again occipital alpha rhythm. Brainproducts Brainamp DC (set for 10MO input impedance) was used for the acquisition of the EEG signals in all 11 experiments.

Results

For prototype1, the impedances with the skin measured as low as 25 kO (vs. gel: 2kO; vs. pin-array electrode: 60kO), depending on the pressure level. Conditions' separability estimated with leave-one-out cross-validation of linear classification on spectra densities of 1 second long segments was: 96%, 71%, 79%, 89%, and 93%. For the coated polymer bristles prototype2, the impedance with the skin measured as low as 30kO for medium-to-high pressure (fully bearable) and typically 80kO for low, unobtrusive pressure on the scalp through the hairs. The spectrum for the best subject is shown in Fig.1b. The eyes open/eyes closed conditions separability was 92%, 80% and 79%. The t-test values for the N100 AEP effect were p=10^-4 for 20 trials and p=10^-8 for 100 trials.

Discussion and Conclusions

In this contribution, the results of using new, metallic and coated polymers bristles electrodes in the acquisition of the EEG in paradigms related to BCI have been reported. Those bristle-sensors outperform electrically the regular array of pins dry EEG electrodes, while providing better comfort to the subjects, creating the premises for longer term use in BCI applications. Authors' research on bristlesensors continues - there are already good preliminary results on auditory P300 ERP with two subjects.

Keywords

Dry electrode, EEG electrode, bristles, N100, ERP, alpha rhythm Disclaimer: The opinions expressed herein are the personal views of the authors.

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C-6 A LabVIEW-based Modular Extension for BCI2000

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Background and Objective

BCI2000 is an open-source software package written in C++ that can be used for brain-computer interface (BCI) research. Given the speed of modern computers, the capabilities of BCI2000 can be fully utilized and enhanced by coupling it with LabVIEW's powerful development environment. The libraries provided by LabVIEW for tasks such as user interface design, networking, visualization, and signal processing allow users to quickly develop custom modules for their research needs. Within the correct framework, these modules could be seamlessly integrated with BCI2000. The multi-thread execution inherent to LabVIEW also gives the ability to easily perform parallel processing.

Methods

We have created a LabVIEW framework that can communicate efficiently with BCI2000. Signal acquisition and spectral analysis is done with BCI2000 and the resulting data is sent via UDP to LabVIEW in compact binary format. This data is translated and passed to a signal processing module in LabVIEW, which can then create a control signal to pass on to an application module. Data flow and execution between the modules is controlled by a self-repairing TCP token ring that is automatically established when both modules have been launched and program execution started. As with the design and practice of BCI2000, at any given time main program execution can be suspended and either or both modules can be switched out. For example, a new application paradigm can be inserted without losing any of the established parameters in a signal processing module. All relevant data is continuously streamed into a LabVIEW TDMS file, with any modifications to module parameters saved when the change occurs.

Results

Our initial testing shows that the developed framework is both a reliable and effective means of extending the capabilities of BCI2000 to allow easy development of powerful custom modules for both BCI and neuroscience research. Using spectral data sent from BCI2000 at a frame rate of 30 Hz, a signal processing module consisting of both a normalized linear classifier and visualization tools, and an application module with a 3D cursor control task executes fast enough (block time <30 ms) that no BCI2000 data is lost. Either module can be easily switched without affecting the other module or program execution.

Discussion and conclusions

The presented framework could provide a valuable way for researchers to develop custom paradigms and harness the full power of both BCI2000 and modern computers. LabVIEW-based signal processing modules can allow users to easily visualize in real-time important information such as spatial-frequency maps or electrode grid activation. Signal processing parameters established during screening tasks are not lost if a new application module is inserted. Additionally, this framework provides the opportunity for further and faster paradigm development through the creation of additional modules that take full advantage of the advanced features offered by the LabVIEW development environment. Once development is completed, it is hoped that this framework and any established modules will prove a useful complement to BCI2000.

Keywords

brain-computer interface, LabVIEW, modular, real-time visualization

C-7 Integration of an Extensible Modular Graphical User Interface with openBCI

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Background and Objectives

Good software practice dictates that a clear distinction is defined between layers in modular hardware and software architectures. Distinguishing clearly between services provided, module interfaces and protocols permits separate development of collaborating components. In addition a good graphical user interface (GUI) should be intuitive, easily learned and extensible. Menu content and structure should be separated from the modules architecture and from navigational mechanisms. Many brain computer interface (BCI) research groups have developed dedicated applications which have proved capable of environmental interaction. In order for such applications to be fully utilised it is necessary to interface to modules which specialise in their given task. To do this in a meaningful manner suggests that some standardisation in BCI based interface design is required. As an example we discuss the successful integration of two such components which have originated from separate research groups.

Methods

A BCI based intuitive graphical user interface (IGUI) was developed within the BRAIN project for the purpose of offering control mechanisms for applications, devices and utilities within a smart homes environment for persons with neurophysiologic disorders. The principle underlying the IGUI design is to offer an effective user interface which can service multiple technologies, either smart homes devices or BCI platforms whilst offering display options adapted to the user's capability and needs. This includes selection of menu content, tailoring of display characteristics and potential BCI modalities. The IGUI component was written in Java. In keeping with BCI2000 [1] it is currently designed to link to a BCI application via UDP packets containing control codes. User trials have demonstrated that the IGUI has been successfully integrated to BCI2000, that smooth menu manipulation is possible and that device control has been achieved. Although the IGUI was initially developed for the BCI2000 platform, it was subsequently harnessed to openBCI. openBCI is an emergent open source platform developed by the University of Warsaw currently implementing SSVEP. Public demonstrations have utilised openBCI when controlling domotic devices and robots. It is designed to be hardware independent and is capable of integrating with software applications from diverse sources.

Results

The ubiquity of the modular design of these two applications has been demonstrated through the seamless integration of both. This required minimal modification of these applications, only consisting of the fine tuning of the communications interface. This new configuration has been shown to be capable of selecting between, and operating simple domestic applications.

Discussion and Conclusions

The simple process of integrating these two applications has helped to demonstrated that good modular design of software in the BCI domain will facilitate future communication and partnerships between BCI research groups. This is readily achieved by enshrining software engineering principles such as clearly defined tasks encapsulated in single software modules, implementing minimum interfaces and using recognised communications protocols. For this strategy to be successful on a wide scale basis standardisation is required. This process was begun by [2] to be fully effective, it now needs to be considered in detail by the BCI community and adopted by diverse research groups.

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Keywords:SSVEP, openBCI, user interface

C-8 DataRiver - a software platform for real time management of multiple data streams

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Background and objective

Modern approaches to studying the brain functions are increasingly focusing on situations in which the subject is acting in a context as unrestricted as possible. This means that it is imperative to record synchronously with the EEG activity a multitude of behavioral, neuro-physiological, and environmental parameters. A major hurdle is that systems that are capable to collect data form different sources do not exist. Rather, each modality is handled by specific instrumentation, often from different manufacturers, and recording and synchronizing data from more than one source is a daunting task.

Methods

DataRiver was designed to overcome those difficulties by creating a device-independent mechanism for data synchronization and management in real time that is unparalleled in its flexibility. It opens up possibilities for unique experiments, never thought possible before.

Results

DataRiver is a modular real-time system for management and synchronization of data coming from experiments involving bioelectric signals (such as EEG, EMG, etc.), and relevant elements of the experimental environment (e.g., event markers, 2-D and 3-D position data, eye position, breathing, EKG, external device data, etc.). The primary goal while developing it was to create a powerful, flexible, and easily configurable and expandable system to support cutting-edge research, such as aimed at neural mechanisms of active cognition, volition, decision-making, spatial orientation, etc. The modular architecture of DataRiver allows new features to be added easily when needed. Plugins, supporting new input devices, as well as output (analysis and feedback) modules are easy to develop using the DataRiver application programming interface (API) to C++, ObjectPascal, and Matlab. The individual, as well as the aggregate streams are available for analysis in real time, via the API. Additionally, DataRiver can interface in real time with Matlab, for which a DataRiver client (MatRiver) real-time library is being developed (see accompanying poster). Feedback can be easily programmed using Producer ?an experimental environment management module, also part of DataRiver, which features a simple, yet powerful script language.

Discussion and Conclusions

The flexibility of DataRiver derives from its modular design ?data output by a variety of hardware devices are handled by specialized device drivers that convert each of them into a device-independent data stream. Those streams are then continuously merged together in real time into a “data river.? Appropriate device drivers, currently available for several types of data input devices and systems, allow easy development of a wide range of interactive experimental paradigms. Data in incoming data streams can be used in real time by “stream recipient?modules for recording, real-time data processing, and/or stimulus control. DataRiver has built-in support for a real-time data exchange with remote computer(s) in a local area network (LAN), allowing a distributed, cooperative experimental environment. Using the API, new features can easily be added at, thus ensuring expandability. DataRiver provides cross-platform support for all three components of a complete biofeedback system ?data acquisition, real-time data analysis (via MatRiver or custom-developed data processing modules), and feedback (via Producer), which makes it a powerful tool for programming brain-computer interface applications.

Keywords

BCI, biofeedback, synchronization.

C-9 BCILAB: A BCI/EEG Research Framework

Christian Kothe*, Arnaud Delorme, Thorsten Zander, Scott Makeig

BACKGROUND AND OBJECTIVE

BCI has seen a performance jump over the past decades, mainly driven by the now-ubiquitous machine learning paradigm. The tools which enabled these advances, such as CSP and LDA, are, however, now starting to inhibit further progress in performance, usability and applications. Hence, new directions are being considered, like the use of more flexible models (Tomioka and Müller, 2009), of more data from other sessions (Fazli et al., 2009) or the incorporation of better prior knowledge from the neurosciences—for improved precision, training times and robustness. Here, we present a novel open-source MATLAB toolbox for BCI research, designed against this background. It will serve as a productivity tool for the design and evaluation of new BCI approaches while remaining accessible to BCI newcomers and experimental scientists, and merges the tools from signal processing and machine learning with those from the neurosciences in one environment, allowing to cross unhindered between the disciplines.

METHODS

BCILAB builds on the PhyPA BCI toolbox (Kothe, 2009), developed by Kothe and Zander, and integrates with EEGLAB (Delorme and Makeig, 2004), connecting to its data analysis and visualization tools. Its core is a lightweight user-extensible component framework, comprising signal processors, feature extractors and learning/prediction functions, including standard tools as well as recent methods such as time/frequency heuristics like Spec-CSP and advanced classifiers like Relevance Vector Machines. The component library is accessed from an online processing API, allowing to plug the toolbox into BCI experimentation platforms (plug-ins for BCI2000, OpenViBE and DataRiver/MatRiver forthcoming). The other main access point is a user-facing exploration, evaluation and training layer, with features from nested and inter-subject cross-validation to custom evaluation metrics. The BCILAB GUI and script interface are integrated with EEGLAB, providing standard and custom visualizations and giving access to methods such as ICA/dipole decomposition, which can break down a predictive model into its supporting cortical regions for interpretation or knowledge discovery. It also enables a novel way to handle robustness and specificity, when models are probabilistically conditioned on region semantics (as, e.g., pulled from Talairach-like databases).

RESULTS

The underlying PhyPA toolbox has been validated in research over several years, in passive BCI applications in HCI (e.g., Zander et al., 2008), in Neuroscience (Gärtner et al., 2008), Games (Kothe, 2009), on classical as well as hybrid active BCI applications (e.g., Vilimek and Zander, 2009), and other studies.

CONCLUSION/OUTLOOK

BCILAB is a data exploration and BCI design, implementation and testing platform, providing extensible functionality from simple "demo" applications to advanced state-of-the-art designs. It offers an environment where BCI models and data can be inspected from a neuroscience perspective, profiting from the EEGLAB ecosystem and hopefully accelerating BCI research. Of interest primarily for the EEG/Neuroscience community is the ability to employ the unique capabilities of BCIs—the computation of optimized explanatory models and moment-to-moment prediction of cognitive state—to uncover relationships between EEG and conditions of interest. An open beta and the initial release are planned for 2010.

SUPPORT

Development of the PhyPA toolbox was funded by Prof. Matthias Roetting and the Berlin Institute of Technology.

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D-1 (C)overt attention and visual speller design

Matthias Treder*, Benjamin Blankertz

Background and Objective

An attention-based visual BCI capitalizes on the fact that spatial attention allocated to a target in an oddball paradigm elicits characteristic deflections in the event-related potential (ERP). However, in ALS patients, oculomotor impairments may impede accurate fixation of the target. Furthermore, in peripheral vision, spatial acuity drops significantly as a function of eccentricity, and resolving an object in the periphery becomes more difficult if it is surrounded by other objects, a phenomenon known as crowding. The aim of this study was, first, to investigate whether ERP-based communication is feasible if the target is not fixated and, second, to investigate whether results can be improved using a speller design that takes into account the limits of peripheral vision. Method We dissociated between an overt attention condition and a covert attention condition. In the latter, participants had to fixate a dot in the center of the screen and allocate covert attention to the target. We also compared the Matrix speller to an adaptation of the Hex-o-Spell [1] which consists of 6 circles placed on a virtual hexagon. Symbol selection is a two-stage process. First, a letter group is chosen. Then, the individual letters of the chosen group are expanded on the circles and the target letter is chosen. Multi-channel EEG and eye movements were recorded while healthy participants (N=13) performed a copy-spelling task. Participants' task was to count occurrences of target stimuli. The experiment was implemented in the open-source BCI framework Pyff [2].

Results

For classification, we used spatio-temporal features and an LDA classifier with automatic shrinkage of the empirical covariance matrices. Note that the classification success in the overt condition was mainly based on VEPs rather than on the P300 component.

Discussion and conclusions

There is a significant drop of performance for covert attention compared to overt attention. Still, offline performance for Hex-o-Spell is in the range of 70% for 10 sequences, demonstrating that communication is possible using covert attention alone. Additionally, we found a consistent advantage of Hex-o-Spell over the Matrix. Hex-o-Spell outperforms the Matrix in the overt attention condition, and it is also less impeded in the covert attention condition. This is probably due to the fact that the Hex-o-Spell contains a few large elements instead of many small elements, and hence is less affected by the drop in spatial acuity and crowding. Moreover, the larger ERP amplitudes observed for the Hex-o-Spell suggest that its elements have a higher stimulus intensity than the Matrix symbols. This might be important because an attenuation of ERP amplitudes is usually observed in ALS patients. Concluding, our results show that visual BCIs using the oddball paradigm can be driven by both overt and covert attention. The design of the speller affects the efficacy of using either mode of attention. The ERP-based Hex-o-Spell will be further developed and validated in an upcoming online study.

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D-2 How Many People are Able to Control a P300/Motor imagery-Based Brain-Computer Interface (BCI)?

Christoph Guger*, Gunther Krausz, Eric Sellers, Massimo Mecella, Guenter Edlinger

An EEG based brain-computer system can be used to control external devices such as computers, wheelchairs or Virtual Environments. P300 based BCI systems are optimal for spelling characters with high speed and accuracy, as compared to other BCI paradigms. Motor imagery or SSVEP-based (Steady-State Visual Evoked Potential) systems are optimal to generate a continuous control signal. In this study, 81 subjects tested a P300 based and 99 subjects tested a motor imagery based BCI system. The subjects participating in the P300 study had to spell a 5 character word with only 5 minutes of training. EEG data were acquired to train the system while the subject looked at a 36 character matrix to spell the word WATER. During the real-time phase of the experiment, the subject spelled the word LUCAS, and was provided with the classifier selection accuracy after each of the five letters. The subjects participating in the motor imagery study had to move 40 times a cursor to the right or left side of the computer monitor. Training and classifier calculation were performed with 40 imaginations of left and right hand movement initiated by an arrow pointing to the left and right side. For the P300 system 72.8 % were able to spell with 100 % accuracy and less than 3 % did not spell any character correctly [Guger 09]. For motor imagery 6.2 % achieved an accuracy above 90 % and 6.7 % performed with almost random classification accuracy between 50-59 % [Guger 2003]. It must be noted that for the P300 system the random classification accuracy is 1/36 % and for the motor imagery system it is 50 %. The training time for both systems was almost equal: 6 min for motor imagery, 5 min for P300 and also the montage time for the electrodes was almost equal (5 electrodes for motor imagery and 9 for the P300 system). This study shows that high spelling accuracy can be achieved with the P300 BCI system using approximately five minutes of training data for a large number of non-disabled subjects. The large differences in accuracy between the two systems suggest that with limited amount of training data the P300 based BCI is superior to the motor imagery BCI. Overall, these results are very encouraging and a similar study should be conducted with subjects who have ALS to determine if their accuracy levels are similar. Summarizing it can be said that a P300 based system is suitable for spelling applications, but also e.g. for Smart Home control with several controllable devices. The motor imagery based system is suitable if a continuous control signal is needed.

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Keywords: P300, brain-computer interface (BCI), motor imagery, ERD

D-3 Brain Painting ?BCI meets patients and artists in the field

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BACKGROUND AND OBJECTIVE

The Brain-Computer Interface (BCI) systems of today have primarily been developed to replace the lost abilities of patients diagnosed with motor-neuron diseases such as amyotrophic lateral sclerosis (ALS). Of these lost abilities, the most important seems to be that of communication [1], represented by the increasing volume worldwide of research and development into such applications. Another valuable element of human life however is that of creative expression. Modification to the P300-BCI communication system has yielded an application which provides the ability for such expression, Brain Painting.

METHODS

Brain Painting [2] works by replacing individual fields in a P300-BCI based control matrix with painting functions, such as cursor control, shape, size and colour selection to produce images of an abstract nature (see Fig. 1). Brain Painting is now used regularly by several ALS patients (n=4) throughout Germany as a form of entertainment and as a way to satisfy the desire for creative articulation in their own homes. Furthermore, prominent German artists (n=6) have been invited to use Brain Painting at their ateliers. Constructive feedback has been collected from these various users in an effort to improve the application. Important metrics being assessed are ensuring the application is intuitive to use, robust in reliability and practical for unsupervised use in daily life.

RESULTS

Quantitative results initially suggest minor performance variations between ALS-patients and healthy subjects. Healthy participants display prominent P300 responses thus requiring 20% less repetitions (12 in comparison with patients (15. A higher repetition of flashes is used to ensure a higher selection accuracy which is valued over speed. Qualitatively are the results outstandingly positive, enthusiastic comments from both patients and artists confirm that importantly they experience satisfaction and are entertained when using the application, with a repeated strong desire to re-use the system. To date, patients using the system have produced numerous images from independent sittings lasting upwards of 1.5 - 2 hours. This is evidence for a BCI solution that serves to satisfy some basic human needs by providing a positive, useful difference and a better Quality of Life to ALS-patients

DISCUSSION AND CONCLUSIONS

Brain Painting satisfies some basic human needs and it is hoped that by providing an ability to be productive again this will assist with improving the Quality of Life for patients with severe motor disabilities. Although the Information Transfer Rate appears low in the Brain Painting application, the high number of stimulus repetitions is a result of a need for a high selection accuracy. During the repetitions the user can concurrently reflect on the next stages and their paintings development. Modifications to the application and stimulus presentation are being initiated to improve the reliability and prominence of the P300 response amongst patients where life sustaining apparatus presents a challenge to the mounting or operation of BCI devices. Thus acceptance of Brain Painting within the artist community and most importantly the patient community is a key factor of the project to ensure its long term success.

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D-4 BCI-Applications: Needs and Requirements of Disabled End-Users and Professional Users

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BACKGROUND AND OBJECTIVE

The EU-project “Tools for Brain-Computer Interaction?(TOBI) aims at developing practical technology for non-invasive brain-computer interfaces (BCI) combined with other assistive technologies (AT) in the domains of communication, environmental control, entertainment and grasping (orthosis). An important concern of TOBI is the close integration of people with disabilities (end-users) and professional users (AT experts and caregivers) in the project. For assessment of the most urgent needs and requirements regarding new ATs, users from different European countries were investigated.

METHODS

TOBI Short Questionnaire: Disabled end-users were asked ?to rate their satisfaction with current AT solutions in the domains of manipulation, communication, computer access, and environmental control on a four-point Likert scale (4= “very satisfied? 1= “not at all satisfied?, ?to indicate whether they had or wanted independent access to devices for communication and entertainment. Professional users and disabled end-users were asked ?to rate the importance of various aspects of AT on a four-point Likert scale (4= “very important? 1= “not at all important?. Participants: The investigated group of 77 disabled AT end-users was very heterogeneous in the etiology of their disability. Diagnosis dated back 15 years on average and participants showed a high degree of impairment (69% were almost or completely tetraplegics) that is, participants represented potential BCI-users. Professional users (n=48) showed a high degree of experience in their professions (years of experience: AT experts: M=9.92, SD?.45; carers: M=12.50, SD?.08).

RESULTS

Satisfaction in the different domains of AT was rather high. However, 30 % of those who used aids for manipulation, were dissatisfied with their current AT solutions. In the domain of computer access 23%, in the area of environmental control 17% and, for communications aids 16% were not satisfied. The majority of the participants had independent access to different devices for communication and entertainment. However, participants who were impaired most severely (tetraplegia, with minimum possibilities to control AT) were in a worse situation. Depending on the device 16%-63% of these participants (n=19) had no independent access. For the less impaired participants (n=58) only 5%-16% did not have access. Professional users and disabled end-users chose the four aspects of “functionality? “ease of use? “possibility of independent use? and “adaptability to the specific situation?as being most important for new ATs. Both, end-users and AT experts rated “functionality?as the most important aspect, while caregivers rated “ease of use?as most important.

DISCUSSION AND CONCLUSION

There is the need for improved AT solutions in the domains where BCI can contribute with applications for manipulation, communication, entertainment and environmental control. The main conclusions for TOBI were to develop BCI applications which will be effective (functional/robust) and simple (ease of use); to train not only end-users in using the BCI-applications but also caregivers in supporting end-users with BCI; to provide AT solutions with which users will be as independent as possible from the support of others and which will be adaptable to the specific situation of the end-user.

SUPPORT

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KEYWORDS

BCI-applications, assistive technology, communication, entertainment, environmental control, orthosis

D-5 User-focused design of a BCI experimentation room

Claudine BOTTE-LECOCQ*, Stéphanie Leclercq, Marie-Helene BEKAERT, François CABESTAING

Today, various experimental BCI systems offer many types of applications to help users overcome a major physical disability by restoring communication, mobility, object handling... Although in rapid expansion, this research field must still be considered at the experimental level, since no widely available BCI system exists for helping people with motor disabilities. In fact, few clinical studies involving patients with severe neurological disorders have been reported in the literature and very few consider disabled patients in everyday life situations. Moreover, several studies comparing the effectiveness of BCI approaches on disabled vs. healthy people report conflicting results . This shows that many more experiments involving physically impaired people are required. Transferring BCI applications from laboratories to dedicated clinical services - and later to patients homes - necessitates before all the specification of perfectly adapted experimental conditions. When we first addressed this problem, because we wanted to setup a room for BCI experimentation, we contacted several researchers from teams in different countries (many thanks again to all the colleagues who answered us!). It appeared that although some obvious constraints about noise, light sources, accessibility, etc, had usually been considered, no team had regarded this problem as a whole. Our study surveys various criteria that one must take into account while designing a room dedicated to BCI experimentation from the ergo-therapeutic point of view, as well as adapted experimental protocols. It is focused on: - constraints about indoor and outdoor access to the BCI room; - arrangement of the room, taking into account various types of physical impairments; - organization of room space for experimenter, subject, third party, equipment; - medical qualification and ratification; - user safety and comfort; - ethical considerations for experimental protocol definition; - ergonomy, etc... Results of this study have been gathered in an internal report that will soon be made available to the BCI community on our web site (for the moment, this report is only available in French). It can be regarded as an exhaustive source of informations, questions, and recommendations for researchers and clinicians who want to setup a BCI experiment in optimal conditions. BCI is a research field that is usually presented either from a technical or medical point of view. Our study emphasizes the importance of the final user, i.e. a physically impaired individual, and the complexity that it implies to place this user at the center of the design problem.

E-1 Control of the P300 Speller using Electrocorticographic Signals

Dean Krusienski*, Jerry Shih

BACKGROUND AND OBJECTIVE

The objective of this research is to demonstrate that electrocorticographic (ECoG) signals can be used to reliably control the P300 Speller [1]. Using scalp-recorded electroencephalography (EEG), the P300 Speller has proven to be an effective and reliable BCI communication paradigm in healthy and disabled individuals [2][4][7]. Most research investigating ECoG BCIs in humans has focused on sensorimotor-rhythm control of computer cursors [3][6]. The use of ECoG for controlling a BCI written communication task has not been previously reported. In this study, event related potentials from ECoG were used to control a P300 Speller via BCI2000 software [5]. ECoG data were pre-processed and used to train a linear classifier to subsequently predict the intended target letters.

METHODS

To date, data have been collected from six subjects with intractable epilepsy who underwent temporary placement of intracranial electrode arrays to localize seizure foci prior to surgical resection. The study was approved by the Mayo Clinic's and the University of North Florida's Institutional Review Board. Each subject sat in a hospital bed and viewed the 6 x 6 matrix display of flashing alphanumeric characters. The task was to silently focus attention on a specified character until the next character was specified for selection. Two 16-channel g.USB amplifiers sampled at 1200 Hz were used for the data acquisition and the presentation/analysis protocol was analogous to [2]. Between 1-3 sessions (~36 characters each) were collected from each subject, depending on the subject's physical state and willingness to continue.

RESULTS

An offline accuracy at or near 100% was achieved using fewer than 15 flash sequences in five of the six subjects tested. One subject achieved a maximum accuracy of 50%, which is suspected to be due to significant hospital distractions during the experiments. In several runs absent of these distractions, this subject's accuracy was near 100%. Four of the six subjects achieved a maximum bitrate of greater than 17 bits/minute at 4-5 flash sequences, while another subject's maximum bitrate was 11.7 bits/minute at 11 flash sequences. A maximum bitrate of 12 bits/minute at 5 flash sequences was computed based on the average accuracy across all six subjects.

DISCUSSION AND CONCLUSIONS

The results indicate that ECoG signals can be translated by P300-based BCI systems to produce accurate and reliable performance at least equal to and likely superior to recordings obtained from scalp EEG. Furthermore, this comparatively high level of performance was achieved on five of six epilepsy patients 1-2 days after electrode implantation. These subjects all had headaches of varying degrees, were on narcotic analgesics, and their sleep patterns were likely fragmented in an epilepsy monitoring setting. Despite all these factors which may degrade test performance, the subjects attained higher accuracy in less trials compared to results from normal volunteers recorded by scalp EEG [2]. In that study, the maximum bitrate corresponding to the average accuracy across five healthy subjects is 7.8 BPM at 9 flash sequences. Further improvements in ECoG-based bitrate could potentially be achieved with optimization of classification parameters for each subject.

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SUPPORT

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KEYWORDS

Electrocorticography, Event-Related Potentials, P300 Speller

E-10 Can synergistic finger movements be represented as the superposition of individual finger movements?

Reinhold Scherer*, Stavros Zanos, Erik Edwards, Kai Miller, Jeffrey Ojemann, Rajesh Rao

BACKGROUND AND OBJECTIVE

Studies have shown that simple, individual finger movements can be decoded from electrocorticographic (ECoG) signals. Real-world situations, however, usually require multiple finger synergies to perform meaningful motor tasks. For brain-computer interfacing (BCI), one way to generate control signals for such synergies is the superposition of ECoG signatures for individual finger movements that are involved in a synergy (e.g. index finger and thumb for pinch). The objective

of this study was to identify and compare the topography of ECoG activities related to individual thumb and index finger movements to that related to pinch.

METHODS

ECoG signals (8x8 grids; 1 cm electrode distance) from 4 epilepsy patients were recorded during cued index finger, thumb and pinch (index and thumb) movements, in a random order (study UW IRB approved). Individual finger movement trajectories, registered using a 5-DOF data glove, were converted into binary movement-state time series (movement templates; 1 for movement and 0 for no movement). Bipolar re-referencing was used to enhance brain activity between neighboring electrodes (distance = 2 cm). The analytical amplitude in the 100-120 Hz band was computed for each of the resulting 306 bipolar channel pairs and correlated with the movement templates for thumb, index finger and pinch. To estimate chance level in the correlation coefficients (CCs), the movement templates were reshuffled (2000 repetitions) and CCs were computed as before; chance level was defined as the maximum CC across all repetitions. Bipolar pairs with CCs smaller than the maximum were rejected.

RESULTS

For 3 out of the 4 subject bipolar channels with significant CCs were located exclusively over sensorimotor cortex. Individual thumb and index finger movements resulted in a lower number of significant CCs and the involved electrodes were topographically more focused compared to pinch. The topography of the pinch activations was more widespread and not predictable from the simple superposition of thumb and index activations.

DISCUSSION AND CONCLUSIONS

The results of this study suggest that multi finger synergies are not the simple superposition of individual finger movements but rather activate additional neural networks. For BCI, this implies that the generation of control signals encoding complex movements for neuroprostheses and artificial robotic arms would likely utilize signal components beyond individual digit superposition.

Support

This research was supported by the National Science Foundation (0622252, 0642848 & 0930908), the Microsoft External Research program, and the Packard Foundation.

Keywords

Brain-computer interfacing (BCI), Electrocorticogram (ECoG), Motor control, Correlation

E-11 Volitional control of cortical neuron activity

Chet Moritz*, Eberhard Fetz

Volitional control of cortical cell activity is relevant for extracting and optimizing control signals for neuroprosthetic devices. We explored the control of single cell firing rates in two male M. Nemestrina by providing visual feedback of neural activity averaged over a sliding 1/2 second window and rewarding changes in rates. During 'brain control?sessions monkeys modulated the activity of each neuron to acquire randomly presented targets requiring progressively higher or lower discharge rates. The monkeys readily learned to control 246 cells recorded from wrist area of both pre- and post-central cortex. Performance improved by more than 2-fold from the beginning of practice to peak performance ($p < 0.0001$). At the beginning of practice with each cell, monkeys acquired 6.4 ?4.5 targets/min using brain control. After an average of 24 ?17 min of practice with each cell, monkeys reached peak performance and acquired 13.3 ?5.6 targets/min. Cell directional tuning was quantified during a 2-dimensional isometric wrist tracking task. For 82 cells with significant preferred directions the monkey performed slightly better in the subsequent brain-control task (15.8 ?5.5 targets/min) compared to the 164 cells with no significant preferred direction (12.0 ?5.2 targets/min, $p < 0.001$). Activity of all cells was modulated substantially more during brain control (21.1 ?12.8 pps) than during wrist tracking (12.7 ?8.1 pps, $p < 0.001$). 1-second averages of cell activity during matching of the high-rate targets increased from 29.4 ?14.5 pps to 39.2 ?25.3 pps over the course of practice. Monkeys could acquire high- and low-rate targets with the same cell with similar success. They could reduce cell activity to match low-rate targets at an average of 86% below baseline cell rates, and increase activity to match high-rate targets 491% above baseline. When recording stability permitted, monkeys practiced controlling cells across multiple days. Performance improved substantially (3.51 targets/min/day) for 27 of 36 cells when practicing brain control over a range of 2-10 days. Monkeys were required to maintain discharge rates within each target for 1s for all cells tested. They were able to maintain discharge rate for an average of 2.1 ?0.7s for 25 cells tested with longer target times, and rates of 6 cells were maintained for 3.0s (the longest time tested). Monkeys performed the brain control task equally well using cells recorded from pre-central cortex ($n = 240$) compared to cells in post-central cortex ($n = 16$). They also demonstrated independent control of all simultaneously recorded pre-central cell pairs ($n = 6$) and triplets ($n = 2$) that were tested, moving a cursor to targets in two- and three-dimensions, respectively. These findings suggest that relatively direct conversion of activity from arbitrary cortical cells to control signals for neuroprosthetic devices may be a useful complementary strategy to decoding intended movement direction.

Support

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E-12 Spatiotemporal dynamics of ECoG activity related to language processing

Xiao-mei Pei*, Eric.C Leuthardt, Peter Brunner, Jonathan Wolpaw, Gerwin Schalk

Background and Objective

Language is an important mental faculty in humans. The use of electrocorticographic (ECoG) signals in humans offers an excellent opportunity for tracking spatial but also temporal patterns of language. It is possible that the detection of imagined speech in ECoG recorded from the cortical surface could be the basis for a BCI system that is powerful, easy to learn, and suitable for widespread dissemination and long-term use. To create the basis for BCI systems based on imagined speech, we have begun to delineate the ECoG features that are associated with actual or imagined speech.

Methods

In this study, we recorded ECoG from 15, 48, or 64 channels in nine patients with intractable epilepsy. We used the BCI2000 software platform and g.USBamp amplifiers. Subjects were presented with one of 36 words either visually or acoustically. The words were monosyllables with consonant-vowel-consonant (CVC) structure and were either consonant- or vowel-matched with each other. The subjects?task was to repeat or to imagine repeating the presented word. Complex alpha (8-12 Hz), beta (18-26 Hz) and high gamma (HG, 70-170 Hz) signal dynamics were observed in three phases of word processing: response to the visual/audio stimuli, actual/imagined word production, and recovery to baseline. To compute these dynamics, we first derived three ECoG features corresponding to alpha, beta and HG power at each electrode and time point. Then, we calculated the signed statistical difference (i.e., signed r2) between speech and rest. Finally, we projected this difference onto a three-dimensional brain model across all the subjects, and thereby showed the dynamic spatiotemporal patterns during speech processing.

Results

ECoG activity within the alpha, beta, and HG band exhibited different spatiotemporal patterns. Activity in the HG band accurately tracked the spatiotemporal dynamics of word processing by marking the relative onset, peak, and offset times of local cortical activation in the three phases, respectively. HG activity consistently increased with speech task in areas surrounding the perisylvian fissure (including posterior superior temporal gyrus (pSTG), posterior middle temporal gyrus (pMTG) and primary motor area (PMA)), in supplementary motor area (SMA), and in Broca's area. Alpha and beta activities consistently decreased with speech task in PMA and SMA. Auditory stimuli induced significant increase in HG activity in pSTG, pMTG, PMA and SMA, modest but significant increase in beta activity in auditory cortex, and significant decrease in beta activity in SMA. Task-associated HG activity was far more spatially specific than task-associated alpha or beta activity. Finally, imagined word production induced significant increase in HG activity at localized foci in pSTG and Wernicke's area, and modest but significant increase in alpha and beta activity in primary somatosensory cortex.

Discussion and Conclusions

This work offers additional evidence that language processing requires the dynamic integration of widely distributed areas of the brain. The results further document the value of ECoG activity in different frequency bands for exploring the neural basis of information processing related to language function. They extend the findings of previous neuroimaging studies of language processing by providing detailed spatiotemporal information, and they indicate that HG activity is of particular value in this regard.

Keywords

Spatiotemporal Dynamics;Neuroimaging;Language processing;ECoG Supported by the US Army Research Office (W911NF-07-1-0415 (GS), W911NF-08-1-0216(GS)) and the NIH/NIBIB (EB006356 (GS) and EB00856 (JRW and GS)).

E-13 Sparse space-time decompositions of ECoG signals.

Connie Cheung*, Charles Cadieu, Lavi Secundo, Edward Chang, Robert Knight, Bruno Olshausen

Purpose

We sought a novel decomposition of electrocorticogram (ECoG) data that is determined by the statistical structure of the data, and not by prior assumptions about the characteristic frequency bands contained within the data. This work is part of our ongoing project to relate behavior to the dynamics of large neuronal populations during cortical processing and communication.

Materials and Methods

Three refractory epileptic patients (18-35 years) had undergone a craniotomy for chronic (1-2 weeks) implantation of a subdural 8 ?8 platinum–iridium electrode array. ECoG signals were sent to a clinical monitoring system and a custom-recording system. Subjects used a stylus on a touch-screen connected to a laptop computer to perform center-out target-directed arm movements. The activity of the ECoG signal was modeled through a linear generative model in which sparse hidden causes produce temporal patterns [Olshausen 2002]. In the model, the sparsely active causes are each convolved with a temporal-pattern, called a basis function. We used unsupervised learning to adapt the basis functions to the statistics of the ECoG signal. By imposing a sparseness penalty, the model is forced to use as few causes as possible to account for the ECoG signal.

Results

A total of 64 basis functions were derived to represent the ECoG signal. The model is able to represent the signal with a small number of causes per time point, ~2-5. Analyzing the causes with respect to arm movement shows that several basis functions are strongly active when the arm is moving. This strong correlation in behavior is seen in both averaged activity and in single trials. In addition, a simple spectral analysis of each basis function indicates that many basis functions learn structure in high-gamma. Furthermore, a number of basis functions reveal coupling between two or three frequency bands (ie. between alpha and gamma).

Conclusion

We have learned a novel decomposition of ECoG signals into a set of sparse basis functions and causes. The learned basis functions share some properties with standard space-time decompositions, but they have unique properties that are dictated by the underlying structure of the ECoG data. The activation patterns of the sparse causes are correlated with arm movement and may improve BMI techniques. The activity of the sparse causes may be indicative of the underlying dynamics of large neuronal populations during cortical processing and communication.

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E-14 Feedback Control of the Spatiotemporal Firing Patterns of Neural Microcircuits

Karim Oweiss*

Jianbo Liu 1), Hassan K. Khalil 1), Karim G. Oweiss 1,2) 1) Department of Electrical and Computer Engineering, Michigan State University, East Lansing, Michigan, U.S.A 2) Neuroscience Program, Michigan State University, East Lansing, Michigan, U.S.A Bidirectional communication between the central nervous system (CNS) and artificial devices is an important element in the design of next generation of Brain Machine Interface (BMI) systems. Artificial delivery of information to CNS is commonly achieved using microstimulation, which often requires precisely controlling the spatiotemporal firing of neurons to elicit a desired pattern of activity in the presence of many unobserved inputs. Our long-term objective is to develop an integrated, closed-loop feedback control system that delivers a multi-site, precisely controlled microstimulation pattern to achieve effective spatial and temporal control of the activities of large neuronal ensembles, and to guide the structural changes of abnormally altered neural circuits for long lasting restoration of its normal function. As a first step towards a more systematic approach to the system design, we explored the feasibility of using multivariable feedback to precisely control the spatiotemporal firing patterns of a set of Globus Pallidus (GP) neurons in a basal ganglia circuit model. The results suggest that properly designed Multiple-Input-Multiple-Output (MIMO) feedback controller can force a subpopulation of observed output neurons to follow a prescribed spatiotemporal firing pattern despite the presence of unobserved inputs. The accuracy of the spike timing of the controlled neural firing with respect to the reference spike trains is in the order of tens of milliseconds. These results also indicate that even a simplified model identified based on knowledge of the functional connectivity between neurons can help in the process of controller design, for example, by prescreening potential stimulation sites and analyzing the nominal stability of the closed-loop system. It remains to be investigated whether such a simplified model can be effective in modeling large scale neural circuits for the purpose of control given some notable differences between the analytic results obtained from the simplified model and the detailed model simulation. Future research will also need to address the long term stability of the closed-loop system under slowly evolving network structures, for example, caused by activity-dependent synaptic plasticity. Understanding the network effects of microstimulation and precisely controlling the firing pattern of neural circuits may greatly facilitate the bidirectional communication between the central nervous system (CNS) and the neural prostheses, help develop more advanced demand-driven closed-loop stimulation paradigm for long term cure of the symptoms caused by neural circuit disorders, and empower new neurorehabilitation strategies that incorporate multi-site microstimulation to promote functional recovery after brain injury. This work was supported by NINDS grant NS054148.

E-15 CORRELATIONS BETWEEN CORTICAL ACTIVITY AND CONCURRENT BEHAVIOR VARY WITH CONTEXT

Chad Boulay*, Xiang Yang Chen, Yi Chen, Lu Chen, Rong Liang Liu, Jonathan Wolpaw

Background

Brain-computer interfaces (BCIs) use cortical activity to define the actions the BCI user wants to perform. This strategy is based on the evidence that cortical activity is closely correlated with intended movement, and the observed correlations are typically used as the starting point for BCI translation algorithms. However, these correlations are usually defined under highly controlled laboratory conditions. Thus, it is not clear how well they will generalize to the complex highly variable real-life conditions in which practical BCIs need to operate. Furthermore, the inconsistent performance typical of current laboratory BCIs suggests that the correlations between cortical activity and intention are affected by a variety of as yet undefined factors.

Objective

The objective of this study was to compare the correlations between a simple measure of cortical activity and a simple motor behavior under two different conditions.

Methods

We examined in awake behaving rats the correlation between electrocorticographic activity (ECoG) over sensorimotor cortex and the H-reflex (the electrical analog of the monosynaptic spinal reflex) of the soleus muscle under two different conditions. In Condition 1, concurrent soleus excitation (measured as electromyographic activity (EMG)) was constant. In Condition 2, concurrent soleus excitation varied over a wide range. For each condition, we correlated ECoG RMS amplitude in three frequency bands (Mu/Beta: 5-25 Hz; Low Gamma: 40-80 Hz; High Gamma: 100-245 Hz) with H-reflex amplitude.

Results

When soleus EMG was constant, low- and high-gamma correlated negatively and mu/beta correlated positively with H-reflex amplitude. In this condition, ECoG reflected cortical activity that inhibited the H-reflex pathway, perhaps presynaptically. However, when soleus EMG varied over a wide range,H-reflex amplitude was not correlated with amplitude in any ECoG band. In this condition, low- and high-gamma were positively correlated and mu/beta was negatively correlated with soleus EMG. Because the H-reflex is larger when soleus EMG (and therefore motoneuron excitability) is higher, the two influences on H-reflex amplitude reflected by ECoG and soleus EMG, respectively, counteracted each other. As a result, ECoG and H-reflex amplitude were not correlated.

Discussion and Conclusions

The results have important implications for BCI applications of cortical signals. They imply that, if cortical activity is assumed to indicate intent, ECoG activity indicates the intended H-reflex gain when soleus EMG is constant, but does not do so when it varies. The correlation between cortical activity and a simple motor function identified under one condition does not transfer to another condition. Successful practical applications of BCIs will require translation algorithms that adjust to (or are unaffected by) the widely varying cognitive and behavioral conditions of daily life.

E-2 Neural decoding with steady-state Kalman filter

Wasim Malik*, Emery Brown, Wilson Truccolo, Leigh Hochberg

Background and Objective

The Kalman filter is commonly used in brain-computer interfaces to infer intended movement from neural activity [1] and has been used successfully in pilot clinical trials of the BrainGate investigational neural interface for people with tetraplegia [2]. Adequate for many BCI applications, the Kalman filter may be too computationally intensive for real-time decoding of large-dimensional signal sets, such as those obtained from multiple recording arrays or comprising multiple signal types. If the stochastic properties of the dynamical system are approximately constant, the optimal Kalman filter gain converges rapidly, which leads us to test whether a low-complexity Kalman filter implementation with steady-state gain computed a priori might be sufficiently accurate for neural decoding.

Methods

Neural data was obtained from a 55 year old woman with tetraplegia using a 10x10 array of intracortical microelectrodes placed in the left precentral gyrus arm representation. Spike trains were recorded while the participant simulated two-dimensional motion control of a computer cursor in a center-out task comprising an initial 6 minute open-loop training phase followed by a 10 minute closed-loop assessment phase. The adaptive Kalman filter was trained using the training data from 29 sorted units, and was then used to decode the neural data and drive the cursor. During offline analysis, the non-recursive eigenstructure method was used to solve the discrete algebraic Riccati equation and compute the steady-state filter gain [3]. The recorded closed-loop neural data was used for offline reconstruction of cursor trajectory with the adaptive and steady-state Kalman filters.

Results

1) Decoding accuracy: With offline neural decoding of the closed-loop data, we confirmed that the Kalman filter gain converges to a steady-state value within about 15 iterations. Negligible differences were observed during the first few seconds between the cursor velocity estimates obtained with adaptive and steady-state filters, after which the estimates were identical, with R2 = 0.99 and RMSE = 0.03?sec over the 10 minute length of data. 2) Computational efficiency: For a BCI state space model with s kinematic states and an n-unit ensemble, the algorithmic complexity of an adaptive Kalman filter for each decoding iteration is cubic in n when n>>s. This cost can be prohibitive for large n or high signal sampling rate. In contrast, the complexity of the steady-state Kalman filter is only linear in n. We empirically confirmed that the efficiency improvement due to the steady-state approach is substantial. In decoding our 10 minute length of spike data with 50 msec timebins, the steady-state approach decreases the program execution time from 23 sec to 0.5 sec, reducing the computational complexity by a factor of 40.

Discussion and Conclusion

Our analysis establishes that the steady-state Kalman filter can markedly increase the computational efficiency for even relatively simple neural spiking data-sets. This is valuable for the implementation of both online neural control tasks and offline performance analyses. This far more efficient neural decoding approach will thus facilitate the practical implementation of future large-dimensional, multi-signal and wireless neural interface systems.

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Keywords

Kalman filter, neural decoding, state space models.

E-3 Cortical Activity During Motor Movement, Motor Imagery, and Imagery-Based Online Feedback

Kai Miller*, Gerwin Schalk, Eberhard Fetz, Marcel den Nijs, Rajesh Rao, Jeffrey Ojemann

Background and Objective

Previous studies have shown that motor imagery can play a crucial role in skill learning, e.g., in learning new skills in sports and overcoming the effects of neurological conditions. Motor imagery has also been used recently to build “brain-computer interfaces?for paralyzed patients. Human brain imaging studies using fMRI and EEG have shown that motor imagery activates many of the same neocortical areas as those involved in planning and execution of motor movements. How these imagery-related responses in the motor system change during imagery-based learning has however remained largely unquantified. In our submission, we address this important question using electrical signals from the surface of the cerebral cortex obtained using electrocorticography (ECoG) in eight human subjects. These subjects had undergone placement of intracranial electrode arrays to localize seizure foci prior to surgical treatment of epilepsy.

Methods

In an initial set of experiments, 8 subjects performed an interval-based task in which they alternated between several seconds of either hand or tongue movement and several seconds of rest in response to visual cues. The subjects then repeated the movement task, except that instead of moving, they were instructed to kinesthetically imagine making that movement during the cue period. Four subjects participated in an imagery-based learning task, in which the magnitude of cortical activation at a particular electrode was used to control a cursor on a screen during motor imagery. Based on the cortical changes seen in the simple movement/imagery tasks, amplitudes at particular electrodes and frequencies were chosen as features that controlled the speed and direction of 1-dimensional movement of a cursor on a computer screen. Non-movement during imagery was verified by EMG, dataglove measurement, and observation. Primary motor cortex was identified with electrocortical stimulation.

Results

We provide quantitative evidence demonstrating that the spatial distribution of ECoG activation for motor imagery overlaps significantly with that elicited by actual movement. These changes were most robust in primary motor cortex. Imagery typically elicited smaller magnitude activation than actual movement (~25%). However, when imagery was used by the subjects to control a cursor on computer screen, the resulting feedback caused a significant augmentation of cortical activity as the subject learned to control the cursor. After feedback training, imagery-related cortical activity frequently exceeded the magnitude of cortical activation observed during overt movement.

Discussion and Conclusions

Our results are among the first to document activation in the human brain as it rapidly adapts imagery-related neural responses using visual feedback during imagery-based learning. This finding provides new insights into why motor imagery is particularly effective in learning new skills in sports and overcoming the effects of debilitating neurological conditions. Additionally, our results provide a quantitative neurophysiological foundation for understanding the successes achieved recently in the use of motor imagery in brain-machine interfaces.

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E-4 Development of a closed loop BCI system using epidural LFP signals from the rat somatosensory system

George Dimitriadis*, Eric Maris, Han Langeslag

Background

Current BCI systems are mainly of two types, invasive ones that use single and multi-unit recordings mostly from the motor system [1] and non invasive ones that use EEG, MEG and fMRI to detect higher brain functions [2]. Lately, electrocorticographical (ECoG) data from human epileptic patients with implanted grids have demonstrated the potential of using epi- and subdural grid recordings for BCI [3]. These systems promise high spatial resolution coupled with recordings from large cortical areas.

Objective

In our lab we are developing a closed loop BCI system based on recordings of epidurally implanted polyimide electrode grids on the somatosensory cortex of the rat. Such a system takes advantage of the fact that grid implantation has been shown to be a stable and long term solution for invasive recordings of brain activity [3,4]. At the same time, in contrast to the wire recording systems, we are targeting a large part of the somatosensory cortex of the rat. This allows us to derive BCI compatible bits of information from subject controlled switches of basic cognitive functions like expectation, attention and intention based on distributed cortical physiology. On the other hand, epidural recordings outcompete non invasive BCI systems because of their significantly higher spatial resolution. Finally the use of a high-density grid (32 channels in our setup) will allow us to construct a 2 way BCI system by using some of the channels for stimulation while at the same time recording from the remaining ones.

Methods

In our setup, we must obtain recordings from a freely behaving subject, while at the same time controlling sensory stimulation. We developed a behavioral setup that makes use of the rat's tendency to nose poke, allowing us to present tactile stimuli to the rat's upper lip in a controlled way. While stimulating this part of the rat's body, we record from that part of the somatosensory cortex that processes this sensory input. Due to the novelty both of the invasive recording system and the behavioral setup some serious technical challenges were presented. The target area of the rat's somatosensory cortex is not directly accessible due to large jaw muscles at the lateral side of the skull. This lead to the development of a lengthy implantation operation in which the polyimide grid is inserted in a lateral way between the skull and the dura onto the target area. We also developed a novel headstage that provides long term connection of the 36 wire ribbon to the recording system while allowing the animal to move freely.

Results

We have recorded data from freely behaving animals, demonstrating the proof of principle of our design. Preliminary analysis has shown that these data sets carry rich information that potentially can be translated into BCI signals. One example of this information is the observed coupling between the instantaneous amplitude of a 40Hz oscillation in one channel with the phase of a 3Hz oscillation in another spatially remote channel.

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E-5 Changing gears from extracellular field potential recordings to in-cell recordings by extracellular multi electrode array

Micha Spira*

Micha E. Spira, J. Shappir and Aviad Hai.

Background and objectives

Multi-Microelectrode-Arrays (MEAs) are increasingly-used for recording in parallel electrical activity from many neurons, for days and months. The devices used for both in-vitro and in-vivo recordings share common advantages of monitoring extracellularly without inflicting mechanical damages to the neurons. The main disadvantage of extracellular electrodes is their low signal to noise ratio. Therefore, the use of extracellular electrodes is limited to recordings of field potentials generated by action potentials. Single excitatory or inhibitory sub-threshold synaptic potentials or membrane oscillations cannot be detected by currently used extracellular-electrode technologies. Here we report on the development of a novel approach in which extracellular MEA system provides “in-cell recording?of sub-threshold synaptic potentials, and action potentials, from individual neurons with signal to noise ratio that matches conventional intracellular recordings (Hai et al., 2009 Nature Methods in press). We refer to the method as “in-cell recording by extracellular micro electrodes? to differentiate it from intracellular recording in which the electrode tip is forced through the plasma membrane to form direct contact with the cytosole (as is the case of sharp electrodes or the whole-cell patch configuration)

Methods

For the experiments, identifiable neurons isolated from Aplysia were cultured on an array of multi gold-mushroom shaped microelectrodes (gM?E ~1?m in height, and “dome?diameter, and 0.5?m stalk diameter), functionalized by a peptide with multiple RGD repeats (R=arginine, G=glycine, D=aspartic acid) (Spira et al 2007, Hai et al 2009a, b). One of the neurons was impaled by a sharp glass microelectrode for both current injection and voltage recordings. Care was taken to ensure that impaling of the cell did not exert mechanical pressure that compressed the neuron against the substrate.

Results

Slightly altered monophasic-shaped action potentials with amplitude of 25-50mV or subthreshold postsynaptic potentials of ~2mV generated by intracellular stimulation were recorded by the gM??. To correct the frequency response of the individual gM?? and the AC amplifiers, we used conventional capacitance compensation methods . Both raw recordings, and the capacity compensated one, were very similar in shape and amplitude to those recorded intracellularly. The coupling coefficient of the neurons with the gM?? ranged between 0.25-0.5 for spikes and long depolarizing or hyperpolarizing current pulses.

Discussion and conclusions

Analysis and computer simulation of the unprecedented results revealed that key to the multi-electrode-array “in-cell recording?approach is the outcome of three converging cell biological principals: (a) the activation of phagocytotic-like mechanisms in which the neurons are induced to actively engulf gold-microelectrodes in the form of micro-mushrooms that protrude from a flat substrate. (b) The generation of high seal resistance between the cell’s membrane and the engulfed gM??, and (c) the autonomous localization of single voltage independent ionic channels (Ohmic conductance) into the patch of plasma membrane that faces the gM??. The use of the “in-cell recording?approach to study cultured neuronal networks and in vivo systems is expected to facilitate basic research and the use of neuroprosthetics for clinical applications.

E-6 Cognitive brain functions for BCI: promise of sophisticated interfaces

Erik Aarnoutse*, Mariska Vansteensel, Dora Hermes, Frans Leijten, Peter Van Rijen, Nick Ramsey

Background and Objective

Brain computer interfaces (BCIs) are being developed in order to offer patients with severe paralysis a means of communication with or control over their environment. To date, most BCI solutions employ ?rhythm changes in the motor cortex, generated by imagined movement. Alternative networks are a recent focus in BCI research, since motor imagery BCI may not provide an optimal solution for all paralyzed patients. An interesting candidate for BCI solutions is the cognitive control network. This well studied network shows clear fMRI activation during working memory tasks at frontal and parietal gyri, which makes it available for prelocalization. In addition, the cognitive control network is highly under conscious control and is very adaptive, suggesting that patients may quickly learn to employ the system for BCI control.

Methods

We measured gamma band activity in ECoG signals during a BCI cursor control task. Subjects were patients who suffered from medically intractable epilepsy and who received electrode grid implantation for diagnostic purposes. For each patient, a single electrode was selected, based on fMRI and ECoG localizer tasks, and used for BCI control in a two-target task during several runs. During each trial of the two-target task, the patients tried to move a cursor towards a target in the upper-right or lower-right part of a computer screen by counting backwards (up) / mental calculation (up) or by relaxing (down). Vertical movement of the cursor was controlled entirely by the ECoG ? power (55/65 ?95 Hz) of the preselected electrode.

Results

We demonstrate that several brain regions involved in the cognitive control network can be used to control a BCI with: the dorsolateral prefrontal cortex (DLPFC), the parietal cortex and the anterior cingulate cortex (ACC). All patients were able to obtain good cursor control (>80% correct, chance level is at 50%) within 1 ?12 covert sessions of 4 minutes.

Discussion and Conclusions

Our data demonstrate that the cognitive control network is a highly interesting source of signals for BCI purposes. In literature, it has been indicated that there may be a topographical diversity of modality and process-specific WM functions within the involved regions. We expect that when high-resolution surface

electrode grids become available for chronic implantation in humans, signals that are subject to cognitive control over very selective mental processes including deliberate reasoning and planning, can be registered and decoded for use in BCI applications. Support: NWO and STW Grant UGT7685
Keywords: cognitive control, ECoG, prefrontal cortex, parietal cortex, anterior cingulate cortex

E-7 High-field fMRI for localization of electrode implant sites for BCI: a study on visual attention

Nick Ramsey*, Jeroen Siero, Josien Pluim, Max Viergever, Patrik Andersson

Introduction

Recent developments in Brain-Computer Interface solutions for totally paralysed patients are moving towards implanting electrodes in specific parts of the brain in humans. A major caveat in this development is a lack of reliable indicators of where to position electrodes to get an optimal electrical signal for BCI. Moreover, localization of the best regions is more critical for minimally invasive surgery, where electrodes are placed in the cortex or on the surface of the cortex through a small hole in the skull. The accuracy of functional MRI in prelocalizing target regions is limited due to contribution of signal from draining veins. In the present study we investigated a new BCI solution where we use brain activity associated with visual attention for BCI control, and image brain activity with a 7T human MRI system. Visual attention is an attractive function to use for patients who cannot move their eyes due to neuromuscular disease or brainstem stroke. A 7T system was used to reduce contribution of draining veins (where signal is expected to be absent due to the very short T2*), with a high resolution to enhance spatial detail. Real-time feedback was tested in 7 healthy subjects to assess feasibility of using 7T fMRI for prelocalization of visual attention regions for implant of electrodes for BCI in paralysed patients.

Methods

Seven healthy subjects were scanned using a 7T Philips Achieva scanner with a 16-channel headcoil. The functional data were recorded using an EPI sequence. The FOV was selected so it covered the occipital lobe. The visual stimuli were constructed as two rectangular areas left and right in the peripheral visual field with a scrolling checkered pattern. In the centre was a marker on which the subjects were instructed to fixate their gaze at all times. The centre marker was alternated between a right arrow, a left arrow and a circle indicating on which side to focus the attention and when to rest (attend centre). Each experiment consisted of 500 volumes where the first 200 volumes were statistically analyzed on the fly to locate the activated regions. During the remaining 300 volumes the subject got feedback based on the activity in these located regions. The first volume was used as the template for motion correction and all the subsequent volumes were rigidly aligned to it in real-time. To find the activated voxels in real-time without the need of interrupting the scan before starting the feedback we implemented the incremental GLM method described in [2]. Two regressors representing right and left sided attention were included in the model. The contrasts "right minus left" and "left minus right" were used to identify voxels of interest for the feedback task. When the localization part was finished the final t-maps were used for making the ROIs representing right- versus left-sided attention. Both ROI's baseline were estimated by averaging the signal in the ROI in the data recorded during the rest condition. In the feedback part of the scan we gave the subjects real-time information on their performance based on the activity in the ROIs. A green instruction marker indicated a correct classification while red represented the opposite. During feedback, each new volume was registered in real-time and online detrending was applied to all voxels in the ROIs individually. The detrended values were averaged to give a single value per ROI. These numbers were in turn normalized (using the baseline estimation) and subtracted to give the value of the control signal.

Results

The control signal, derived from the contrast based on the ROIs obtained from the localizer task, was compared to the task (sequence of events where the centre stimulus indicated attend left, right or center in the feedback task). Average correlation was 0.71. Performance on the task (i.e. whether subjects managed to get arrows to turn green) was dependent on the threshold chosen for the control signal. Realtime performance was mediocre due to a too stringent threshold, but offline selection of an more appropriate thresholds yielded very good results (>80% hit rate). Adjustment of the threshold during feedback was applied in 2 additional subjects, yielding these good performance levels as expected. In conclusion, 7T fMRI localization of visual attention regions yields excellent results in a feedback experiment in healthy controls. It carries great promise for presurgical localization of target foci for placement of electrodes for BCI in paralysed patients. [1] Brefczynski, J. A. et al. Nat Neurosci 2: 370-374 (1999), [2] Bagarinao, E. et al. Neuroimage, 19(2):422-429 (2003).

E-8 INRIA Cortex team-project: BCI activities

Laurent Bougrain, Carolina Saavedra*, Baptiste Payan, Axel Hutt, Maxime Rio, Frédéric Alexandre

Our activities concerns information analysis and interpretation and the design of numerical distributed and adaptive algorithms in interaction with biology and medical science. To better understand cortical signals, we choose a top-down approach for which data analysis techniques extract properties of underlying neural activity. The following activities are directly linked to Brain-Computer interface challenges. 1. Template-based classi?ers to detect evoked potentials We develop template-based classi?ers to robustly detect efficiently transient events, e.g. evoked potentials, in a single trial from noisy and multi-sources electro-encephalographic (EEG) signals [1]. In this context, we have extended the learning vector quantization (LVQ) algorithm to non-identity assignment to robustly detect evoked potentials for brain-computer interfaces (BCIs). The improved LVQ is obtained by optimizing its assignment layer using the minimum-norm least-square algorithm, the same scheme used by extreme learning machine (ELM). The proposed algorithm improves the accuracy with less computational units compared to original LVQ and ELM. 2. Decoding Finger Flexion from ECoG in Brain-Machine Interfaces (BMI) We develop data analysis techniques to extract properties of underlying neural activity from multi-electrode recordings for direct BMIs for the control of a skilled hand movement. We won the international BCI competition IV, datasets 4, on the prediction of individual ?nger ?exion from electro-corticogram (ECoG) using amplitude modulation in speci?c bands. We built a linear decoding scheme based on bandspeci?c amplitude modulation with a window to the past for predicting ?nger ?exion from ECoG signals. The sensitivity pro?le of ECoG is clearly band-speci?c. The gamma band (60-100Hz) seems to provide more useful information. Only a few features are useful. A half-second window through the past improves the prediction [2]. 3. Detection of synchronization in Local Field Potentials It is supposed that the interaction mechanism between brain areas is based on the synchronization of the dendritic activities in the areas. Since Local Field Potentials (LFPs) re?ect this activity, we focus on the study of LFPs obtained experimentally to better understand the inter-area information exchange. We investigate the synchronization of LFPs obtained intracranially from various monkey brain areas. The corresponding experiment combines visual attention and motor action and thus allows for the study of the visio-motor feedback loop. The data analysis [3] aims to detect time windows of increased phase synchronization between brain areas and relates these time windows to the monkey behavior. 4. Detection of event-related components in single trial EEG In cognitive experiments, typically the experimental task (one trial) is repeated many times and the resulting brain activity is averaged over trials. The main reason for this averaging is the low signal-to-noise ratio (SNR) in the single trials and average increases the SNR dramatically. The average activity allows to extract easily event-related components, which are strongly related to cognitive processes in the brain. However, this averaging assumes that the brain responds to the external stimuli identically in all trials. However it has been shown in several previous studies that this assumption is not valid. Consequently, to improve the analysis we develop an algorithm to extract event-related components from single trials. This algorithm is part of the PhD-project of Maxime Rio. It is based on a Gaussian mixture model and is implemented in a Bayesian framework. Main collaborations : The STIC Amsud project (2009-2010) BCI “Robust single-trial evoked potential detection?The participants are: the Laboratory of Engineering Rehabilitation and Neuromuscular and Sensorial Research (L.I.R.I.N.S), Facultad de Ingeniería, Universidad Nacional de Entre Ríos, Argentina ; The Department of Biomedical Engineering, Valparaíso University, Valparaiso, Chile ; The Computer Science Department, Federico Santa María University, Valparaiso, Chile ; The Laboratory of Neuro Imaging Research, Autonomous Metropolitan University, Mexico DF, Mexico. OpenViBE : We develop with the INRIA Bunraku team-project an open-source software for Brain-Computer Interfaces and Real Time Neuroscience (http://openvibe.inria.fr).

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E-9 Rapid Brain-Based Communication Using Electrocorticographic Signals (ECoG)

Anthony Ritaccio*, Peter Brunner, Joseph Emrich, Horst Bischof, Gerwin Schalk

BACKGROUND AND OBJECTIVE

Many people affected by neurological or neuromuscular disorders such as amyotrophic lateral sclerosis (ALS), brainstem stroke, or spinal cord injury, are impaired in their ability to or even unable to communicate. A brain-computer interface (BCI) uses brain signals directly to restore some of the lost function. A BCI approach that several groups have begun to test in clinical applications in humans (e.g., [1,2]) is the matrix-based speller originally described by Farwell and Donchin [3]. This speller makes use of different event-related potentials (ERPs) including the P300 evoked response. In this system, the user focuses on a character in a matrix while each row or column is intensified rapidly and randomly. The BCI can learn the desired character by detecting the row and column that produces the largest evoked response. While this approach is faster and more robust than many other BCI approaches, it is still relatively slow. For example, while recent electroencephalography (EEG)-based studies [1,4] reported high spelling accuracy (6x6 matrix of 36 characters; 79% to 83% accuracy, 2.8% chance), the spelling rate in these studies was limited to one character selection every 13 to 42 seconds. At this rate, conveying a single message (e.g., several words) takes several minutes. Thus, such BCI systems may only prove useful to people with severe paralysis. Extending the number of people that can benefit from BCI technologies requires further improvements to the current communication rate. A growing number of recent studies (e.g., [5,6]) suggest that signals recorded from the surface of the brain (electrocorticography (ECoG)) are a promising platform for BCI communication. This promise is based in part on the improved signal quality of ECoG compared to that of EEG [5,7]. This improved signal quality of ECoG should result in increased BCI communication performance.

METHODS

In this study, we investigated this possibility by testing the communication performance of the matrix speller implemented in the BCI2000 software system [8] using ECoG signals recorded from frontal, parietal, and occipital areas in one human subject. BCI2000 was first calibrated using data from a 5 minute run. Subsequently, the subject performed seven runs for 35 minutes of data collection (444 selections total).

RESULTS

During these seven runs, the subject corrected all errors and we continued to optimize system performance. Using 2 stimulus repetitions and a stimulus duration of 3/64 sec (47 ms), the subject sustained a selection every 3.5 seconds (i.e., 17.1 selections per minute) at 86.4% accuracy. This accuracy/rate corresponds to a sustained rate of 69 bits/min. In a final run, the subject spelled at rate of 2.75 seconds/character (i.e. 22 characters/minute or 113 bits/min). Statistical analyses (two-sample t-test) revealed statistically significant ($p<0.0001$) evoked responses between 125 and 175 ms post stimulus over wide cortical areas in secondary visual cortex, associative visual cortex, angular gyrus and somatosensory association cortex. DISCUSSION AND CONCLUSION The results of this study suggest that ECoG may support communication performance that is substantially higher than does EEG. Thus, with additional verification in more subjects, our results could further extend the communication options for people with serious disorders.

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KEYWORDS

BCI, P300, matrix speller, ECoG

F-1 EOG Artifact Correction for Brain-computer Interface Application Using GALME-ICA

Cota Gupta, Ramaswamy Palaniappan*

Background and Objective

It is an established fact that neurological activity is a useful source of control in any brain-computer interface (BCI) system and artifacts are undesirable signals. We present a novel technique to reduce electrooculogram (EOG) artifacts that corrupt electroencephalogram (EEG) signals in BCI applications. Method We introduced the basic idea of genetic algorithm based independent component analysis (GA-ICA) and applied it to reduce additive noise from biomedical signals using kurtosis [1]. Following on this idea to develop an efficient framework which reaches better solutions and hence better performance, we implemented and tested a Genetic Algorithm using Large Mutation rates and population Elitist selection (GALME) [2] replacing genetic algorithm. In traditional GA-ICA as implemented in [1], low mutation is usually a background operator and it is usually crossover which improves the performance. GALME uses large mutation to produce offspring's that are as different as possible from their parents, to examine regions of search space not yet explored. Gradually decreasing mutation rates enables GALME to find better fitness values by performing local search, using good solutions obtained. The presented GALME-ICA uses mutual information (MI) as a fitness function to reduce the EOG artifacts which corrupt the recorded EEG channels. It also reduces correlation between the recorded EEG channels. Data corrupted with eye-blinks used for this work were obtained from the BCI competition IV website (Graz data set 2B). EEG channels (C3, Cz and C4) corrupted with eye blinks recorded at the beginning of the session from file B0202T were used.

Results

The performance of GALME-ICA was compared with that of Fixed Point ICA, Amuse ICA and Sobi ICA algorithms; it is seen that GALME-ICA achieves lower PSD values for all three channels and therefore higher EOG artifact reduction. The maximum value of power spectral density (PSD) for EEG signal with EOG artifacts was 17.91 (at 3 Hz, corresponding to eye blink activity). The peak values of PSD obtained after GALME-ICA, Amuse-ICA, FP-ICA and Sobi-ICA were 9.11, 10.78, 12.97 and 11.2 respectively.

Discussion and Conclusion

In this work we have presented a fully automated method to reduce EOG artifacts for offline BCI analysis which shows improved results compared to other ICA methods . However care should be taken in tuning the parameters of GALME so that it does not converge to a local minimum. A repetition of several runs might also be necessary to obtain good solutions and the execution time for the proposed framework is higher than that of ICA algorithms. For future work, classification of the BCI competition IV (Graz dataset 2B) will be performed after reducing the EOG artifacts using the developed method. Keywords: Brain-computer interface; Electroencephalogram; Electrooculogram, Genetic algorithm; Independent component analysis

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F-2 EEG Dynamics associated with Human Motor Control in Patients with ALS or PLS

Ou Bai*

Background

Patients are usually required long-term training for an effective EEG-based brain-computer interface (BCI) control, and may be easily fatigued due to the focused attention during the prolonged BCI operation. We have proposed a user-friendly BCI that requires minimal training and less mental load, based on the EEG rhythmic dynamics between event-related desynchronization (ERD) and event-related synchronization (ERS) associated with human natural motor control performed by either motor execution or motor imagery. We have successfully tested the proposed novel BCI methods in healthy controls. In this study, we want to test whether ERD and ERS associated with human natural motor control are available in patients with motor neuron diseases; further, whether patients may achieve reliable BCI controls by voluntary natural motor actions without extensive training.

Methods

The initial tests were investigated in three patients with amyotrophic lateral sclerosis (ALS) and three patients with primary lateral sclerosis (PLS), who had no previous BCI experience. All patients performed binary control of cursor movement (Bai et al. 2008); One ALS patient and one PLS patient performed four-directional cursor control in a two-dimensional domain (Huang et al. 2009) under a BCI paradigm associated with human natural motor behavior; motor execution and motor imagery. Subjects received about 5-10 minute practice and the multi-session study of either binary control or four-directional control including online BCI game were completed within 1.5 ?2 hours in a single visit.

Results

ERD and ERS in beta band were observed in all patients during the production of voluntary movement either by motor execution or motor imagery. The online binary control of cursor movement achieved an average accuracy about 82.1?.2% with motor execution and about 80% with motor imagery, where offline accuracy was achieved 91.4?.4% with motor execution and 83.3?.9% with motor imagery after optimization. In addition, four-directional cursor control had accuracy about 50-60% with motor execution and motor imagery.

Discussion and Conclusion

Patients with ALS or PLS may achieve BCI control without extended training, and the fatigue might be reduced during the operating BCI associated with human natural motor behavior. The development of a user-friendly BCI will promote practical BCI applications in paralyzed patients. Keywords: EEG, Event-related desynchronization (ERD), event-related synchronization (ERS), motor imagery, dynamics, motor neuron disease

F-3 Classification of Adaptive Autoregressive Models at Different Sampling Rates in a Motor Imagery-Based BCI

Martin Billinger*, Clemens Brunner, Christa Neuper

Background and Objective

Autoregressive (AR) models have been employed for feature extraction in brain–computer interfaces (BCIs) using either AR coefficients directly [1], or the estimated spectrum [2]. Considerable effort has been put into finding suitable settings for model order and adaptive update coefficient. The model order p is equal to the number of past observations from which the current sample is predicted. From the perspective of spectral analysis, p/2 frequency peaks can be resolved with a given model. The frequency resolution of an AR spectrum depends on the time window of length p/fs spanned by the AR model [2]. To increase the length of the time window, the model order can be increased, which may lead to an overfitted spectrum. Alternatively, reduction of the sampling rate fs does not change the number of AR coefficients, but limits the maximum frequency. This work demonstrates the improvement of motor imagery (MI) classification by reducing the sample rate in an offline study.

Methods

An offline study was performed using the last of 5 sessions from BCI Competition IV, data set B [3]. The data contains 80 trials of each left and right hand MI with feedback from 9 trained subjects. Three bipolar EEG channels (C3, Cz, C4) were recorded with a sampling rate of 250 Hz. The signals were resampled from 245 Hz down to 5 Hz in 5 Hz steps, using a least squares linear–phase filter with a Kaiser window to prevent aliasing. At each sampling rate a Kalman filter implementation of an adaptive autoregressive (AAR) model was fitted to each channel, using model order p = 6 and update coefficient UC ?10-5 . A linear discriminant classifier was applied to the AR coefficients. At each step the classification accuracy was estimated by 10 x 10 cross–validation.

Results

At sampling rates lower than 25 Hz classification accuracy dropped below chance level for 6 out of 9 subjects. One particular subject showed a prominent rise of 10.3 % in classification accuracy at sampling rates below 125 Hz. Two subjects were not able to perform above chance level. Averaged over all subjects, classification accuracy has a maximum of 77.6 ?14.2 % at a sampling rate of 75 Hz. This is an improvement compared to 75.1 ?13.4 % at 250 Hz. The difference is significant with $p < 0.05$, according to a left–tailed paired t–test.

Discussion and Conclusions

The ?rhythm is modulated by motor imagery in a frequency band of 8?2 Hz. At sampling rates lower than 25 Hz most of the task–relevant portions of the EEG are removed. This could explain the drop in classification accuracy. Increasing the model order or reducing the sampling rate can improve spectral resolution [2]. In contrast to reducing sample rate, increasing model order leads to a higher number of features, which may inhibit the classifier's ability to generalize. Although the average improvement was only 2.5 %, reducing the sampling rate has the potential to considerably improve the classification rate of individual subjects.

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Support

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Keywords

brain–computer interface (BCI), electroencephalogram (EEG), motor imagery (MI), autoregressive model, sampling rate

F-4 rtMEG: A Real-time Software Toolbox for BCI2000 Using Magnetoencephelography

Gustavo Sudre*, Wei Wang, John Kelly, Tao Song, Matti Kajola, Ramana Vinjamuri, Jennifer Collinger, Alan Degenhart, Anto Bagic, Doug Weber

Background and Objective:

Magnetoencephalography (MEG) is a non-invasive method to study brain functions with high temporal and spatial resolution. There is an increasing interest in studying the potential use of MEG for brain-machine interfaces (BMI) research. To date, the majority of studies have performed offline analysis to reveal detailed information about the spatial and temporal evolution of neural activity as it relates to a task, or to measure neuroplasticity resulting from an intervention. However, real-time MEG feedback could benefit many areas of research, including BMI. Currently there is no available method to capture the large amount of information from a 306-channel Elekta Neuromag?MEG system in order to provide real-time feedback.

Methods

We have developed a toolbox that can stream in real-time MEG signals from a 306-channel Elekta Neuromag?MEG system to any computer. Our MEG toolbox is integrated with BCI2000, a widely used open source software package for BMI research and development [1], and it can be easily configured to relay the real-time signal in binary format to any arbitrary host in the network. Because the rtMEG toolbox was written as a source module in the BCI2000 system, any researchers already using BCI2000 in their experiments can simply reuse their module pipeline and exchange the source module with the rtMEG.

Results

Preliminary results indicate that signals can be processed with minimal delay (<30 ms) in a setup with 324 channels of data (306 MEG channels plus additional measurements such as EMG and EOG) sampled at 1000 Hz, which is sufficient for many real-time BMI studies. Moreover, in a task that simulated the modulation of amplitude in two frequency bands using a function generator, the high degree of similarity between signals recorded by the MEG system and the toolbox was demonstrated in both frequency and time domains.

Discussion and conclusions

This toolbox can be a valuable tool for real-time BMI research using the 306-channel Elekta Neuromag?MEG system, including studies of neurofeedback training for stroke and spinal cord injury rehabilitation, and other general neuroscience research. For example, researchers will be able to test various neural processing, decoding, and user training paradigms “on the fly?within a single MEG session. The rtMEG toolbox also enables a faster evaluation cycle, creating the opportunity for dynamic or adaptive paradigms, which is a powerful alternative to the traditional way of doing neuroscience research. Furthermore, one may be able to use MEG as a tool for real-time brain mapping, or as a pre-surgical tool to localize the optimal placement site for an ECoG grid for obtaining real-time BMI control. The toolbox will be made available to the scientific research community as open source along with the BCI2000 software, and we hope that it can be used to support many new areas of real-time MEG research.

Keywords

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F-5 Exploiting prior neurophysiological knowledge to improve Brain Computer Interface performance

Arne Ewald*, Andreas Ziehe, Forooz Shahbazi, Guido Nolte

BACKGROUND AND OBJECTIVE

Most EEG based Brain Computer Interfaces (BCI) employ machine learning techniques to discriminate and classify the recorded data belonging to different classes. Usually, no neurophysiological knowledge is used within the classification algorithms. Here, a method is proposed that includes prior knowledge about the locations of sources of imagined movement of the left and the right hand by projecting EEG data onto a subspace defined by modeled sources at the corresponding loca-tions in somatosensory areas. The aim is the reduction of artifacts and therefore an improvement of the BCI performance. II.

METHODS

The modeled sources are located 2.5 centimeters beneath the electrodes ‘C3?and ‘C4?in radial direction with respect to the head’s curvature as event-related desychronization (ERD) is chosen as the applied BCI paradigm. Three different source models are investigated. First, one radial dipole on each hemisphere is based on the assumption that both location and orien-tation of the sources are known. Hence, for two sides, a 2-dimensional subspace is selected. Second, three dipoles at each location span a 6-dimensional subspace assuming known locations but uncertain orientations. Third, we modeled the sources as multipoles up to quadrupolar order resulting in a 16-dimensional subspace. The multipole expansion systematically cor-rects for inaccuracies both in location and exact shape of the source. After the projection onto respective topographies, feature extraction is performed on the reduced data by Common Spatial Filter (CSP) analysis. Finally, Linear Discriminant Analysis (LDA) is applied for classification. III.

RESULTS

The projection of the data should lead to a reduction of the dimensionality of the signal focusing on those parts which are generated or suppressed in the motor cortex during imagined hand movement and to a reduction of artifacts. When the sources are modeled as a single dipole or as three dipoles per hemisphere the performance strongly decreases for most of the subjects. This observation changes by modeling the sources as multipoles. It is shown that a projection with respect to source locations prior to CSP analysis leads to a gain of BCI performance when the sources are modeled as multipoles. The performance of 16 out of 24 investigated subjects increased by the apply-ing the described technique.

DISCUSSION AND CONCLUSION

When sources are modeled as dipoles only, the reduction of dimensionality leads to a loss of relevant data needed for the spatial analysis (CSP) and therefore to a decrease of BCI performance. Since the exact locations of the sources vary a little from subject to subject, it is also likely that the assumed locations do not exactly match with the real source locations. This can be compensated by applying the multipole source modeling technique, because the additive terms of the quadrupoles effectively introduce a spatial extent of the sources and diminish the effect of misplacement. Within this study it is shown that exploiting prior knowledge about source locations is capable to improve BCI perform-ance.

To further enhance this technique one can think of calculating user specific source locations that can be used for a prior projection.

Keywords

BCI performance, Source modeling, Multipoles, Event-Related Desynchronization, Common Spatial Patterns

F-6 Effort toward Zero Training in Brain-Computer Interface using Beamforming Source Imaging

Minkyu Ahn, Sungwook Kang, SUNG JUN*

Background and Objective

Brain Computer Interface (BCI) is mainly divided into two parts; calibration phase for training and feedback phase. Because the signal state of subjects and experimental settings could be different every experimental session, regeneration procedure of spatial filter and classifier is required in general. However, this pre-procedure is likely to raise subjects?fatigue at the early stage. For more convenient and applicable BCI system it should be investigated to reduce preparation time before feedback session. Beamformer is a source imaging technique widely used in MEG/EEG source localization problem. It passes only signals produced at the designated source point and filters out other signals such as noise. We conjecture information in source space may be more discriminative than that in sensor space because recorded sensor signals are physiologically originated at sources. In addition, features in source space could be far less variable (almost steady) over session-to-session. This can easily facilitate to use existing data together with new data. In other words, in place of sensor signals, source space projected signals by beamformer could be more flexible in developing adaptive classifier of BCI since pre-recorded signals could be re-used. In this work, we investigate how zero training would be achievable by projecting sensor space onto source space. ?

Methods

We collected 2-class conditioned EEG data during several sessions under the same subject and the same experimental paradigm. For each session, common spatial pattern (CSP) and Fisher linear discriminant analysis (FLDA) based BCI classifier was generated and its performance was assessed. Then every trial collected from several sessions was projected onto pre-defined voxel space by beamformer. From all projected trials, one CSP and FLDA based classifier was generated to assess the performance. Two types of BCI classifiers (sensor space type BCI and source space type BCI) were compared in success rate. Since beamforming source space projection can increase the number of channels (voxels in source space) as large as possible, we tried to do comparative study for various sizes of voxels such as the number of sensors (p), 2p, 3p, and 4p. ?

Results

We found that as a whole, sensor space type BCI classifier trained with all trials for several sessions performed slightly worse than ones trained with trials for individual session. It is evident that each session does not retain consistent features even for the same subject. After projection, source space type BCI classifier trained with all trials for several sessions is comparable in performance to ones for individual session. This result is supportive that inter-session variability of features in source space seems to be small, thus collected data among sessions can be more usable in developing the same BCI system. ?

Discussion and Conclusions

Minimizing preparation time for BCI system is necessary to improve practicability of BCI. We found that source space projection could reduce inter-session variability, thereby saving preparation time. Recently, BCI system to resolve inter-subject variability is of great interest. It is under the investigation how our proposed source space type BCI could be effective between subjects. ?

Support

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Keywords

Beamformer, Brain-Computer Interface, Localization, Source space type BCI

F-7 Feature Extraction from High-Impedance EEG Recordings Using Maximum Noise Fraction

Zachary Cashero*

Background and Objective

The majority of current approaches to brain-computer interfaces (BCI) focus mainly on wet electrode recordings. Although this produces a fairly clean signal, there are still some interference issues with these electrodes, and, more importantly, this requires a relatively long preparation time. Research has been done to develop dry electrodes that do not require the use of a conductive gel which greatly reduces the setup time. Dry electrodes are an essential step in developing a more practical EEG recording device. While most of the current research focuses on custom electrode designs which couple an amplifier with the electrode, we will take the approach of developing software algorithms that can extract features from the true EEG signal in the presence of a large amount of noise and interference. Although the focus is on dry electrode recording, more robust analysis techniques can also be applied to wet electrode recording especially when in an uncontrolled environment that can cause a lot of interference.

Methods

The recordings were done using wet and dry passive electrodes simultaneously. Using a 19-channel cap, ten of the electrodes were dry on one side of the scalp while the nine electrodes on the opposite side were wet. The data was collected using a Mindset-24R EEG amplifier. The subject performed four tasks: actual left hand movement, actual right hand movement, eye blinks, and eyes closed to induce alpha waves. Data from the wet and dry electrodes will be analyzed separately to find the amount of correlation between the two. Maximum noise fraction (MNF) will be used in order to find the components that contribute to the signal while filtering out the noise components. The same recording procedure will be performed using the Biosemi system in order to assess the efficacy of the active electrodes in eliminating noise.

Results

Results will show whether or not our current signal separation methods are able to extract meaningful EEG from the very noisy signals recorded from high impedance connections. We expect the extraction of hand movement signals to be more difficult than the extraction of eye blinks and alpha waves.

Discussion and Conclusions

These experiments are initial attempts to extract meaningful EEG from dry electrodes. Tests with MNF for signal separation will show whether or not it is possible to find recognizable EEG patterns in a very noisy situation. Conclusions will be made regarding the relative success we achieve with EEG recorded by the Mindset amplifier versus the Biosemi amplifier.

G-1 Ethical Issues in Brain-Computer Interface Research

Mary-Jane Schneider*, Jonathan Wolpaw

Brain-computer interface technology (BCI) has the potential to provide communication and control to people severely disabled by amyotrophic lateral sclerosis (ALS), brainstem stroke, cerebral palsy, and other neuromuscular disorders. In BCI technology, the electrical signals produced by subjects?brains are recorded and translated by computer software into output that allows subjects to fulfill their intentions to communicate or to manipulate their surroundings. A number of laboratories in the U.S. and other countries have developed the technology to the point that a limited number of patients have been able to use it in everyday life to communicate with caregivers, send and receive e-mails, and change TV channels. Other potential uses include manipulation of prosthetic arms and legs using signals from the motor cortex, control of a motorized wheelchair, and in other ways control of the environment. This paper examines possible ethical concerns in the conduct of research on BCI technology in light of the axioms of ethical action: to do good, to not do harm, and respect for autonomy. Various kinds of BCIs may pose risks of a variety of harms, including physical risks, emotional risks, risks of miscommunication, concerns about violation of privacy, and discomfort with the prospect of “cyborgs.? However, the technology has many potential benefits, including enhancement of the autonomy of the disabled individual, which persuade us that the research should continue under societal and technological controls, with strict procedures for informed consent.

H-1 Visual Cue Design in Brain Computer Interfaces

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Visual Cue Design in Brain Computer Interfaces Mst Kamrunnahar, Andrew Geronimo, Steven J. Schiff
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Background and Objective

The objective of this work was to study the differences in motor imagery task-related scalp electroencephalography (EEG) in response to stimuli balanced and unbalanced in the subject visual field. Most visual cues in brain computer interface (BCI) applications are unbalanced in the subject visual field. Some examples include: center-out cursor control, center-out arrows, flushing of letter-numbers, and cues in virtual reality environment application. However, yet to be answered question is: what is the optimal size, shape, or placement of a visual cue in a BCI application? In this work, we investigated issues such as: (i) how stimuli balanced vs. unbalanced in the visual field affect EEG signal power, (ii) what is the timing of the difference in EEG features due to different cues, if any, (iii) how does the difference impact task discrimination, and (iv) what are the conditions under which the difference can be useful or should be treated as an artifact.

Methods

We designed three different pairs of arrow cues in different sizes and presented them such that they were balanced and unbalanced in the subject visual field. Four subjects (3 male and one female) in the age range of 19-22 years, inexperienced in BCI, participated in the left vs. right hand movement imagery task experiments. Commonly used features such as bandpowers in the mu (8-12 Hz) and beta (16-24 Hz) frequency bands, event related potentials (ERP), and common spatial patterns were extracted from the preprocessed and artifact rejected EEG data. Two different algorithms, forward stepwise and principal component analysis (PCA) with across group variance (AGV) consideration, were applied for feature optimization. A modified version of Fisher's linear discriminant analysis (LDA) was applied for feature classification and motor task discrimination.

Results

Time courses of event related (de)synchronization (ERD/ERS) of electrode channels in different scalp locations helped dissociate visually stimulated signals from the responses due to motor task imaginations. Classification accuracy between rest vs. movement imageries and left vs. right hand movement imageries identified two distinct time periods in task discrimination. In the time period of 500ms within cue presentation, the best discrimination was obtained with unbalanced cues, which is indicative of a visually evoked potential effect. In the time period after 1s of cue presentation, classification accuracy, presumably influenced by motor task imagination, was similar for the different arrow cues.

Discussion and Conclusions

Preliminary results suggest that unbalanced arrows can be used in BCI task discrimination using visually evoked potential (VEP) in the early time period (approx. within 500ms after cue presentation), whereas balanced arrows should be used when power changes in mu/beta rhythms (representing motor imaginary tasks) are considered as features. Further work includes combining visually evoked potentials, attention related potentials, and mu/beta rhythms for feature construction. Support: Grant #K25NS061001 (MK)from the National Institute of Neurological Disorders And Stroke (NINDS)

Keywords

Brain Computer Interface, Visual cue effect, motor imagery tasks, visually evoked potential, EEG features

H-2 Multi-task Learning for Zero Training Brain-Computer Interfaces

Morteza Alamgir*, Moritz Grosse-Wentru, Yasemin Altun

Brain-computer interfaces (BCIs) are limited in their applicability in everyday settings by the current necessity to record subject-specific calibration data prior to actual use of the BCI for communication. In this work, we utilize the framework of multitask learning to construct a BCI that can be used without any subject-specific calibration process, i.e., with zero training data. In BCIs based on EEG or MEG, the predictive function of a subject's intention is commonly modeled as a linear combination of some features derived from spatial and spectral recordings. The coefficients of this combination correspond to the importance of the features for predicting the intention of the subject. These coefficients are usually learned separately for each subject due to inter-subject variability. Principle feature characteristics, however, are known to remain invariant across subject. For example, it is well known that in motor imagery paradigms spectral power in the mu- and beta frequency ranges (roughly 8-14 Hz and 20-30 Hz, respectively) over sensorimotor areas provides most information on a subject's intention. Based on this assumption, we define the intention prediction function as a combination of subject-invariant and subject-specific models, and propose a machine learning method that infers these models jointly using data from multiple subjects. This framework leads to an out-of-the-box intention predictor, where the subject-invariant model can be employed immediately for a subject with no prior data. We present a computationally efficient method to further improve this BCI to incorporate subject-specific variations as such data becomes available. To overcome the problem of high dimensional feature spaces in this context, we further present a new method for finding the relevance of different recording channels according to actions performed by subjects. Usually, the BCI feature representation is a concatenation of spectral features extracted from different channels. This representation, however, is redundant, as recording channels at different spatial locations typically measure overlapping sources within the brain due to volume conduction. We address this problem by assuming that the relevance of different spectral bands is invariant across channels, while learning different weights for each recording electrode. This framework allows us to significantly reduce the feature space dimensionality without discarding potentially useful information. Furthermore, the resulting out-of-the-box BCI can be adapted to different experimental setups, for example EEG caps with different numbers of channels, as long as there exists a mapping across channels in different setups. We demonstrate the feasibility of our approach on a set of experimental EEG data recorded during a standard two-class motor imagery paradigm from a total of ten healthy subjects. Specifically, we show that satisfactory classification results can be achieved with zero training data, and that combining prior recordings with subject-specific calibration data substantially outperforms using subject-specific data only. Keywords: Brain–computer interface, Multitask Learning, Feature Relevance Learning

H-3 Semi-Autonomous navigation based on error-related EEG potentials

Ricardo Chavarriaga*, Xavier Perrin, Roland Siegwart, Jose del R. Millan

Background and Objective

Brain-computer interfaces are typically based on voluntary modulation of brain signals by continuous generation of mental commands (e.g. mental imagery). Such way of interaction is usually highly demanding in terms of cognitive attention and effort. As an alternative, we discuss a new interaction approach where the user only monitors the performance of a semi-autonomous device. In this work we present a navigation system in which a mobile robot carries out its task automatically and proposes one possible action to the user whenever it cannot make a reliable decision because there are several options. That action is selected or discarded based on online detection of error-related EEG potentials (ErrP).

Methods

We develop a robotic system able to navigate autonomously in indoor environments based on sensor inputs. Whenever it reaches a point where several actions are possible (i.e. move forward, turn left/right) it provides feedback to the user proposing one possible action. EEG signals are decoded online to detect the presence of ErrP. 64 channel EEG is acquired at 512 Hz, averaged to CAR and filtered in the range 1-10 Hz. ErrP detection is based on the activity of Fz, FCz and Cz electrodes 100 to 600 ms after feedback. The action likelihood is updated based on the classifier output until a decision threshold is reached; the selected action is executed and the robot resumes autonomous behavior. During online experiments the user remotely commands the robot while observing a video stream provided by an on-board camera. Visual feedback signaling the proposed action is superimposed at the center of the video image. During experimental sessions the subject is asked to navigate towards one out of seven different predefined rooms; Two sessions were recorded using a simulated robot and one using a real robot?5 and 10 goal destinations per session, respectively).

Results

Online experiments on one subject show that it is possible to successfully guide the robot to the target. Recognition of correct robot propositions during online control was about 70% and an average of?4 propositions were required to reach the desired goal. Control experiments show that a system with random classifier performance is not able to reach the goal in less than 100 interactions.

Discussion and Conclusions

We present a semi-autonomous system where EEG-decoded signals provide sporadic cognitive input to an intelligent device. This approach provides a natural way of brain-machine interaction and reduces the user's cognitive load (the system behaves autonomously 82% of the time). Task performance is comparable to other BCI applications based on mental imagery. Moreover, online feedback plays an important role in the interaction as it allows the subject to remain attentive to the task when required and provide reliable brain signals. We currently perform further experiments on this approach, studying the effects of different modalities of feedback and the possibility of improve performance by endowing the autonomous system with learning capabilities. Support: European project FP6-IST-027140 (BACS)

Keywords: Error-related potentials, semi-autonomous systems, mobile robotics, single-trial EEG recognition

I-1 An online-BCI system using hand movement direction recognition from MEG

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Background and Objectives

Using the directional tuning of neural activity to control an artificial effector in a direct motor brain-computer interface (BCI) has been implemented in invasive monkey and human studies [1,2,3]. Recent results indicate, however, that non-invasively recorded brain signals contain substantial information about hand movement direction especially in the low-frequency components [4]. Therefore, the purpose of the present study was to investigate whether these directionally dependent non-invasive signals can be used for on-line BCI control of an external actuator.

Methods

Eight healthy subjects participated in a cued center-out movement task where they had to move a non-magnetic joystick to two predefined target positions “left?and “right? The basic software code for the closed-loop approach was implemented in BCI2000 (http://www.bci2000.org) in combination with a fast data exchange to MATLAB (The MathWorks Inc). Six short calibration sessions (CS) of 50 trials each were used to train an RLDA classifier. For one group (SG group, 4 subjects) the model was then built using the Savitzky-Golay low-pass filtered signals (2nd order, 630ms) of 51 sensorimotor MEG channels. For the other group (BP group, 4 subjects) the 4-6 Hz band-pass filtered signals (Butterworth, 2nd order) served as a feature. Simultaneously EOG, EMG and joystick position were recorded. After aligning the data at 50% of maximum joystick deflection we selected the optimal time point for decoding movement direction from the MEG in a window 630 ms before to 910 ms after this trigger. As a measure of performance the decoding accuracy (DA, i.e. percentage of correctly decoded trials) was evaluated. Following the calibration, subjects performed six brain-control sessions (BS) of 40 trials on day one and additional 12 BS two days later. During all BS the output of the unmodified classifier initially build in CS was shown as a discrete feedback at the end of each trial.

Results

During BS we could infer bi-directional hand movements with significant DA of 65?% for SG group and 77?% for BP group (p<0.01). On average users maintained a stable DA over all BS. DA started to rise above chance level before movement onset and reached its peak around the end of the movement. In contrast to the non-informative EOG the EMG signals also yielded significant DA peaking before movement onset. Topographic analysis of DA during CS revealed a uniform distribution without strong indications for artifacts. Discussions and Conclusions: We have shown that online decoding of hand movement direction from non-invasive MEG signals is possible in a BCI with high performance. Moreover, we found a remarkable stability of DA over days without the need for modifications to the classifier. While the extracted directional information from sensorimotor cortices was not due to eye movements, its precise origin, namely motor or sensory, remains to be unraveled in future experiments.

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I-2 NIRS signals predict SMR-based BCI performance in EEG

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Background and Objective

While NIRS has very recently been shown to be capable of measuring mental states, such as stress in humans [1], this has so far not been applied to the EEG-based BCI context. In this study, we show that NIRS can be seen as a potential source of robustifying EEG-based BCIs in simultaneous imaging recordings.

Methods

The NIRS system used (DYNOT232, NIRx Medizintechnik, Berlin) covers the whole head with 60 probes (30 detectors, 30 emitters), providing a total of 84 channels, (fs=1.9 Hz). Attenuation changes at 760 and 830 nm are converted into changes of [deoxy-Hb], based on a modified Beer-Lambert law. Simultaneously, EEG is recorded (64 channels, sampled at 5 kHz, down sampled to 100Hz). A standard SMR-based BCI paradigm [2] is employed, with an inter-stimulus interval of 6 s. 300 trials are recorded, with short pauses occurring every 20 trials and longer pauses every 100 trials. Bins of 5 trials are generated and EEG-BCI performance within these bins is calculated. The overall performance is subtracted from each 'bin-performance? such that a time course of above and below average EEG-BCI performance is obtained. The NIRS signal is cut into epochs, preceding each 5 trial bin by 10, 20 or 30 sec. Noisy channels are discarded and the signal transferred into the spectral domain. A quadratic ridge regression optimization problem is formulated to identify spectral NIRS features predicting the EEG performance of the following 5 trials. We validate our results by a 10x10 fold cross-validation.

Results

In the 25s epoch we are able to predict whether the following 5 trials will be above average performance in one subject with an accuracy of 70.2 +/- 3.2%. The highest r^2–values of the NIRS data from the two conditions can be found in motor and frontal areas. The significant differences of the two involved regions happen at distinct frequencies, while motor areas show effects at lower frequencies, frontal areas show higher frequency differences.

Discussion and Conclusions

The proposed method is successful in identifying meaningful NIRS features for predicting BCI performance and detecting related mental states. The most significant differences appear in central motor areas as well as in frontal regions. While mainly motor activities are responsible, also frontal activity can be a successful predictor for task engagement, which is in agreement with previous neurophysiologic findings. However, further research is needed in order to utilize this approach, exploiting optical imaging, for the applicability of online BCI experiments directly.

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I-3 Effect of NIRS-based neurofeedback on brain activity during motor imagery

Shin'ichiro Kanoh*, Ko-ichiro Miyamoto, Tatsuo Yoshinobu, Ryuta Kawashima

Background and Objective

Pattern classification or machine learning improves the performance of BCI (brain-computer interface). But generally, such signal processing techniques are not so effective when the measured signal have poor reproducibility (large day-by-day or trial-by-trial variance). In this study, the effect of the online feedback training on the BCI system to detect motor imagery from NIRS (near-infrared spectroscopy) signals measured at the sensorimotor area was investigated. Rich spatial resolution of NIRS is suitable to evaluate the spatial distribution of the brain activation.

Methods

Five subjects were instructed to imagine movement of his/her own right hand for 20 s. Inter-trial interval was randomly varied from 40 to 43 s. During experiments, 52-channel Oxy-/deOxy- hemoglobin concentration rates around sensorimotor cortex were measured (ETG-4000, Hitachi Medical Corporation, Japan). The feedback data was the Oxy-Hb signal averaged over the three channels chosen for each subject from the contralateral (left) hand area. The feedback data was presented to the subject online all the time during experiments by the LCD display as a vertical white bar whose length was proportional to the feedback data. Subjects were instructed to control the length of the white bar by the motor imagery: as long (short) as possible during imagery (resting) period. To evaluate the effect of online feedback training, the change of the following three properties during 5-day training were evaluated, (1) S/N ratio of the response, (2) the integral value of the averaged Oxy-Hb concentration during motor imagery, (3) the spatial representation of the response to motor imagery.

Results

The S/N ratio and the integral value during motor imagery increased on Subjects 1 and 3 by training. This means that the magnitude of cortical activation elicited by motor imagery and its reproducibility was improved by the online feedback training on the two subjects out of five. On Subjects 1 and 5, the Oxy-Hb activation was widely distributed to the whole measured area before starting the online feedback training. But after completing 5-day online feedback training, the cortical hemodynamics became more localized to the corresponding area (contralateral hand area, c.f. "motor homunculus"). These results indicated that the online feedback training improved one or more of the three properties shown above on three subjects out of five (Subjects 1, 3 and 5), and it will help to improve to detect motor imagery by NIRS signal measured from sensorimotor area.

Discussion and Conclusions

On three subjects out of five, it was shown that the magnitude and its S/N ratio of the Oxy-Hb hemodynamics during motor imagery were improved, or the spatial localization of the Oxy-Hb activations became more localized by online feedback training. We have reported that the EEG neurofeedback training enhances the beta band power elicited by motor imagery [1]. The present results suggest that the neurofeedback training using NIRS is effective to improve brain activation during motor imagery and its spatial representation. Experiments to verify the present results with more subjects, and more precise investigations by using multimodal measurements (EEG/MEG, fMRI and NIRS) were left for further study. Reference [1] Shin'ichiro Kanoh, Reinhold Scherer, Tatsuo Yoshinobu, Nozomu Hoshimiya, Gert Pfurtscheller: Effects of long-term feedback training on oscillatory EEG components modulated by motor imagery, Proceedings of the 4th International Brain-Computer Interface Workshop and Training Course 2008, pp.150-155 (2008).

Support

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Keywords

BCI (brain-computer interface), motor cortex, motor imagery, neurofeedback, NIRS (near-infrared spectroscopy)

I-4 Applying supervised Hidden Markov Model for Functional near-Infrared spectroscopy

Patrick Kierkegaard*, Bashar Awwad Shiekh Hasan

INTRODUCTION

Functional Near-Infrared Spectroscopy (fNIRS) is an emerging optical brain imaging technique, which is non-invasive, portable and can provide a spatial map of the brain's functional activity in the form of hemodynamic changes with a reasonably good spatial and temporal resolution. This makes it an attractive alternative for BCI development in comparison to the more traditional EEG techniques. The current research of using fNIRS systems is still in its very young stages and attempts used to classify the recorded hemodynamic signals have been very experimental so far, yielding mixed results . This paper further investigates the possibility classifying fNIRS signals by trying to distinguish between two different levels of mental workloads by using supervised Hidden Markov Model (HMM). The results obtained from these studies indicate that there is possibility of achieving high accuracies of developing a 2-class system when applying fNIRS using HMM for a BCI system.

METHODS

A. Participants Five participants between the ages 22-29 took part in this study. All the participants were healthy students from the University of Essex. B. Equipment and set-up The near-infrared system used was an Oxymon Mk III from (Artinis Medical Systems) comprising of two detectors and two receivers mounted on a custom designed headgear made to hold the optodes onto the participant's forehead. The optodes were positioned on the broadmann area 10 of the prefrontal cortex. C. Procedure Participants were presented with a blank white screen for 60 seconds to measure their baseline recording and instructed to not think of anything. They were then presented with an algebraic mathematical problem and were asked to solve the problem. This procedure was repeated 10 times in total. III. ANALYSIS To classify the ongoing data, a supervised Hidden Markov Model (HMM) approach was used. The data is considered as a two class classification problem, where the rest data is one class and the activation is another class. Every class is model with a 3-state HMM. The states are assumed to be fully connected because we linked studies on the temporal nature of near-infrared data. Maximum-a-posterior (MAP) method is used to train the HMM models. To classify new data, a 6-seconds moving window is used to test the ongoing data stream. For every window, the likelihood of both HMM models is calculated and the model with the highest value is considered to be responsible of generating the window and hence the classification decision is made.

RESULTS

Table 1 shows the results of the previous approach. The presented results are a window-by-window accuracy rather than point-by-point. 4-fold cross-validation test is used to obtain the results . TABLE I. CLASSIFICATION RESULTS Participant Accuracy using Supervised HMM A 71.03% B 68.52% C 71.56% D 69.83% E 95.61% V.

DISCUSSION

The confusion matrix analysis shows some bias towards the activation class, this is due to the imbalanced size of the training datasets of both classes. Other classifiers (GMM, LDA) were tried as well but performed very poorly; this could be credited to the ability of HMM to model the temporal behaviour of the data. This proves the importance of temporal modelling in Near-Infrared data in asynchronous setting as it is in a synchronous one.

J-1 Advanced User-System Interaction: BCI Research at TNO Human Factors

Jan Van Erp*, Anne-Marie Brouwer

Background and Objective

The Netherlands Organization for Applied Scientific Research TNO is one of the largest R&D organizations in Europe. TNO Human Factors develops fundamental knowledge and applies it together with its partners and costumers to improve performance and well-being of both patients and healthy user groups. Advanced user-system interaction is one of our key areas, and we consider Brain Computer Interfaces as a promising technology for both patients and healthy users.

Methods

We have a strong background in multidisciplinary and experimental research, and always take the user's skills and capacities as point of departure when designing user-system interaction. We aim to realize progress in the following tracks: brain-based hands-free navigation, brain-based indices for operator state estimation, improving resilience and reducing stress-related disorders, and brain-based image classification. In each of the tracks we integrate BCI technology (mainly based on EEG and NIRS) with high-end Human Interface technologies we have available. Examples include: 3D audio, visual, tactile and multimodal displays to present probe stimuli in P300-based navigation interfaces, emotion extraction from speech and facial expressions and physiological measures to estimate emotional states, virtual reality and serious gaming environments to develop training and treatments based on neuro-feedback, eye tracking equipment to combine gaze direction, eye movement patterns and brain signals in visual target search, and simulators, and instrumented vehicles to make the transition from lab to operational environments.

Results

Discussion and Conclusions

Our approach from a Human Factors point of view is complementary to that of disciplines like neuroscience and Computer Science. We are aiming to contribute to the following areas: 1. Facilitating the spin-off or broadening of BCI technology from therapeutic applications to people with special needs, the elderly, and professionals working in extreme environments. Many users outside the medical domain could benefit from the technology. 2. Facilitate the integration of BCI sub technologies like neuroscience, computer science, robotics, physiology, psychology, data acquisition and signal processing, hardware development, rehabilitation, and clinical know-how; all disciplines that are part of multidisciplinary Human Factors teams on a regular basis. 3. Create synergy between humans and machines which is one of the main aims of Human Factors, and guide the expected shifts in how users and systems interact and may confluence. 4. Smooth the integration of high-end Human Factors (research) tools into the BCI field, including monitoring physiological and mental state, gaming and simulation, training, entertainment, and Virtual Reality.

Keywords

Human Factors, Computer Science, User-system interaction, Ergonomics, Design-for-all, User-centered

J-2 OpenViBE Tutorial

Anatole Lecuyer, Yann Renard, Laurent Bougrain*, Baptiste Payan, Laurent Bonnet

Summary and Objectives

OpenViBE is a novel, free and open-source software for Brain-Computer Interfaces meant to accelerate research and applications of BCI. We propose a tutorial on OpenViBE to present this novel tool to the BCI community: its features, its use and how to quickly develop new BCI applications with it. OpenViBE: OpenViBE is an open-source software devoted to the design, test and use of Brain-Computer Interfaces. The OpenViBE platform consists of a set of software modules that can be integrated easily and efficiently to design BCI applications. Key features of the platform are its modularity, its high-performance, its portability, its multiple-users facilities and its connection with high-end/Virtual Reality displays. The “designer?of the platform enables to build complete scenarios based on existing software modules using a dedicated graphical language and a simple Graphical User Interface (GUI). This software is available on the INRIA Forge under the terms of the LGPL-V2 license (http://openvibe.inria.fr). Tutorial: the tutorial will make an overview of main characteristics, functionalities and applications of OpenViBE. We will describe how to use OpenViBE, its graphical user interface and its programming tools. We will explain how to write BCI scenarios with OpenViBE, to develop BCI applications without writing a single line of code. We will give illustrative scenarios such as real-time visualization of brain activity in 3D, P300 Speller, and virtual reality and videogames- all based on OpenViBE. Audience: the targeted audience can be both BCI designers and BCI users. No-specific skills in programming are required for the tutorial, which will mainly use the Graphical User Interface of our software. Each participant could use his/her personal computer (LINUX/Windows) with internet connection to install and use OpenViBE before or during the tutorial.

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J-3 A mobile and wireless brain-computer interface for communication in daily life

YIJUN WANG*, YU-TE WANG, TZYY-PING JUNG

Introduction

Moving a brain-computer interface (BCI) from a laboratory demonstration to real-life applications poses severe challenges to the BCI community [1][2]. Recently, with advances in the biomedical sciences and electronic technologies, the development of a mobile and online BCI has obtained increasing attention in the past decade [3]. A mobile BCI has the advantage of ultimate portability as well as a low system cost derived from using customized Electroencephalogram (EEG) recording and signal processing modules. To implement a mobile BCI with online processing, a mobile terminal such as a mobile phone or a PDA might be an ideal platform for data transmission, signal processing, and feedback presentation. In this study, we aim to integrate a wearable and wireless EEG system with a mobile phone to implement a visual-evoked potential (VEP) based BCI, which can be used to directly make phone calls based on users?EEG.

Methods

A typical VEP based BCI using frequency coding consists of three parts: visual stimulator, EEG recording device, and signal processing unit [4]. In this study, a virtual keypad consisting of 12 flickers (indicating 10 digits, backspace, and enter) displayed on a computer monitor was used as the stimulator. The stimulus frequencies ranged from 9Hz to 11.75Hz with an interval of 0.25Hz between two consecutive digits. EEG was measured using a wearable and wireless 4-channel EEG recording module [5]. A head strap with embedded electrodes was used to fix electrode positions over the occipital area. The EEG signal digitized at 128Hz was transmitted to a Nokia N97 (Nokia Inc.) mobile phone via a wireless Bluetooth module. On the phone, a J2ME program developed using Borland JBuilder 2005 in conjunction with Wireless Development Kit 2.5 was installed to perform online procedures including frequency detection of the VEP, feedback presentation, and phone dialing. In the experiments, the users were instructed to dial a 10-digit phone number by looking at the flickered digits sequentially. In each trial, a 512-point Fast Fourier Transform (FFT) with a 1s step was started at 4s to calculate the power spectra of the elicited SSVEP until the same dominate frequency of the VEP was detected twice consecutively. For each digit selection, the sound of the digit was delivered through the cell-phone speaker as auditory feedback and the cue for the next target. There was a 1s interval between trials for the users to rest and shift their gaze directions to the next target.

Results

Ten healthy subjects with normal or correct-to-normal vision participated in the experiments. To facilitate system operation, only one electrode around the Oz site was used for online processing. All subjects completed the dialing task with a mean accuracy of 95.9?.4%. The information transfer rate (ITR) of this cell-phone based BCI system was 28.5?.8 bits/min, which was comparable to other VEP BCIs [4].

Conclusions and Discussion

In this study, we proposed to design, implement and test a mobile and wireless platform for BCI. The portability of the wireless EEG hardware, the ubiquity of cell-phones, and the flexibility of the software implementation make this platform promising for BCI's real-world applications. The testing results demonstrated the feasibility of using this platform for constructing a practical wearable and wireless BCI. Directions for future work include the use of dry EEG electrode [5] and spatial and/or temporal filtering of the acquired EEG data to further improve the system performance.

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Support

The research was supported by a gift from Abraxis BioScience Inc. Keywords: Brain-computer interface, Electroencephalogram, Visual-evoked potentials, Wireless data transmission

K-1 A practical design of the asynchronous BCI based on ERD

Kai Qian*, Plamen Nikolov, Ding-Yu Fei, Ou Bai

Background and Objective:

EEG-based brain-computer interfaces (BCIs) can transform a user's intentions towards an external device or neural prosthesis. BCIs targeted at practical application require asynchronous operation mode, easily implemented algorithms, real time calculation ability. In this study, we proposed a novel paradigm for an online brain-controlled switch based on ERD following an external sync signals. Furthermore, the ERD feature was enhanced by 3 event-related moving averages and the performance was tested online.

Methods

Subjects were instructed to perform an intended motor task following an external sync signal in order to turn on a virtual switch provided on a computer screen during intention control state or task state. No specific mental task was required during the non-control or rest state. The two states alternately appeared. Meanwhile, the beta-band (16-20Hz) relative ERD power (ERD in reverse value order) of a single EEG Laplacian channel from primary motor area was calculated and filtered by 3 event-related moving average in real-time. The computer continuously monitored the filtered relative ERD power level until it exceeded a pre-set threshold selected based on the observations of ERD power range and then turned on the virtual switch.

Results

Four right handed healthy volunteers participated in this study. The false positive rates encountered among the four subjects during the operation of the virtual switch were 0.8?.9%, whereby the response time delay was 37.0?9.5 s and the subjects required approximately 12.3?.5 s of active urging time to perform repeated attempts in order to turn on the switch in the online experiments.

Discussion and Conclusion:

The novel design of the brain-controlled switch using the ERD feature associated with human natural motor intention achieved minimal false positive rate with a reasonable active urging time to activate the switch from online test. The 3 event-related ERD power moving averages provided better features by restraining the noise in the non-control state from offline data analysis. The reliability and convenience of the developed brain-controlled switch may extend current brain-computer interface capacities in practical communication and control applications.

Key Words

EEG-based asynchronous BCI; Event-related desynchronization(ERD); Motor control.

K-2 Subjective rhythmization as a paradigm for BCI

Rutger Vlek*, Rebecca Schaefer, Jason Farquhar, Peter Desain

Background and objective

Subjective rhythmization refers to the induction of accenting patterns in the brain during the presentation of auditory pulses at an isochronous rate. It occurs automatically, as illustrated by the ‘clock illusion? where identical clock sounds (‘tick-tick? induce the percept of a binary accenting pattern (‘tick-tock?, but a pattern can also be voluntarily imposed. We investigate whether this can be used as a mental task to control a brain-computer interface (BCI).

Methods

Five subjects perceived and imagined three different metric patterns (2-, 3-, and 4-beat) superimposed on a steady metronome. EEG was measured and time-domain features of single beats (0.5s) were used to train a binary regularized logistic-regression classifier, distinguishing subjectively accented from non-accented beats. Perception data was also used to train a classifier, while the imagery data was used to test it. A sequence classification method was applied to the predictions of the binary classifier, allowing for prediction of the 2-, 3- and 4-beat patterns of imagined accents. As an alternative to this approach, a measure of periodicity was also explored for classification of longer data segments.

Results

The results show that it is possible to classify imagined accents from non-accents on the level of single beats (0.5s) with an average accuracy of 61.3% over subjects, even with a classifier trained on perception data, in which case the average accuracy is 62.0%. The sequencing approach proved to be useful in decoding the beat patterns with an average accuracy of 49.2% (after 10 trials, 0.5s each, on the 3-class problem). The alternative periodicy classification approach yielded similar results .

Discussion and Conclusions

In our study it was shown that imagery auditory accents in a beat-pattern can successfully be decoded from EEG brain signatures. This makes subjective rhythmization a promising paradigm for an auditory BCI system. It has also been shown that a classifier trained on perception and applied to imagery data performs equally well. This would greatly improve usability of a BCI system around this paradigm, since no explicit instruction of the mental task is needed during training, besides listening. This approach to classifier training may also be of use in other BCI paradigms.

Keywords

brain-computer interface, EEG, subjective accents, sequence classification

Support

This work is supported by the BrainGain Smart Mix Programme of the Netherlands Ministry of Economic Affairs and the Netherlands Ministry of Education, Culture and Science.

K-3 Towards a Fully Interpretable EEG-based BCI System

Fabien Lotte*, Anatole Lecuyer, Cuntai Guan

Background and Objective

BCI research appears as a promising way to improve brain understanding. Unfortunately, current BCI generally behave as “black boxes? i.e., we cannot interpret what algorithms automatically learnt from EEG data. This has motivated the BCI community to stress the need for BCI signal processing and classification techniques from which we could gain insights about the brain dynamics (McFarland06). In this work, we propose a method to design a fully interpretable EEG-based BCI.

Methods

To design an interpretable BCI, we propose to combine interpretable features with an interpretable classifier. We also take advantage of Zadeh’s “computing with words?framework (Zadeh96) to increase the system interpretability by using words instead of numbers. This design method comprises three steps: 1. Feature extraction: We used features based on inverse solutions, which are methods able to reconstruct the activity in the whole brain volume, by using only scalp EEG signals. More precisely, we used the FuRIA feature extraction algorithm which can identify, thanks to an inverse solution, the most relevant brain regions and frequency bands to classify various mental states (Lotte09). 2. Classification: We used a Fuzzy Inference System (FIS), i.e., a classifier able to learn “If-Then?rules describing which input feature values correspond to which output class or mental state (Lotte07). 3. Linguistic approximation: Combining FuRIA and FIS already gives an interpretable BCI that can explain using rules which activity in which brain regions and frequency bands corresponds to which mental state. However, these rules are expressed using numbers and humans are more used to reason with words. Consequently, the last step consists in performing linguistic approximation, i.e., in presenting what has been learnt thanks to words (e.g., “high activity? rather than numbers (Zadeh96).

Results

We performed a first evaluation on data set IV from BCI competition II, containing hand movement intention EEG. Our BCI, combining FuRIA and FIS, reached 85% of classification accuracy versus 84% for the competition winner. Moreover, the automatically obtained rules, expressed with words, clearly explained what was expected by the literature, i.e., that hand movement intention is characterized by a power decrease in the motor cortex contralateral to the hand concerned, in the mu+beta frequency band (Pfurtscheller99).

Discussion and Conclusions

We presented a method to design a fully interpretable BCI. This method relies on the combination of inverse-solutions, fuzzy inference systems and linguistic approximations. Our BCI can explain which activity in which brain regions and frequency bands corresponds to which mental state, thanks to rules expressed using simple words. A first evaluation suggested that the designed BCI reflected knowledge expected from the literature when used on movement intention EEG signals, and had high classification performances. We believe that this interpretable approach could be a useful tool to verify what the BCI learnt and to compare it with the literature on the brain signals analyzed. The rules being expressed with words, they could also prove useful to present the knowledge automatically extracted by the BCI to persons not familiar with classification concepts, e.g., to medical doctors.

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Keywords

Interpretability, inverse solution, fuzzy logic, linguistic approximation

K-4 Sequential operation of a hybrid BCI: combining motor imagery-based and SSVEP-based BCIs

Gert Pfurtscheller*, Teodoro Solis Escalante, Christa Neuper

BACKGROUND AND OBJECTIVES

A typical hybrid BCI is composed of two BCIs, or at least one BCI and another system, and must achieve a specific goal better than a conventional system. This work introduces a hybrid BCI composed of a motor imagery-based BCI and an SSVEP-based orthosis control. The goal of the hybrid BCI is to reduce the false positives during resting periods when the flickering lights of the SSVEP-based BCI are switched off.

METHODS

Participants activated and deactivated the visual stimuli (LEDs flickering at 8 and 13 Hz) of the SSVEP-based BCI using the asynchronous brain switch. Gazing at the 8 Hz LED opened the orthosis and gazing at the 13 Hz LED closed it. Six healthy subjects (age 26.1 ?2.9 years) were instructed to complete the following sequence: (i) activate (close) the brain switch through motor imagery, (ii) complete an orthosis cycle (6 SSVEP commands), (iii) activate (open) the brain switch again, and (iv) keep the brain switch open during a 60 s pause indicated on a computer monitor. The experiment was self-paced and the sequence was repeated 4 times for one run. For comparison, the experiment was repeated without the brain switch (i.e. the visual stimuli were switched on even during the pauses).

RESULTS

Using the SSVEP-BCI alone the false positives per minute (FP/min) were 0.9 ?0.8 during the control periods and 5.4 ?0.9 FP/min during the pauses. In the hybrid BCI scheme, there were 0.8 ?0.9 FP/min and 1.4 ?1.2 FP/min., during control and pauses respectively. Performance of the task was estimated from the precision = true positives/(true positives + false positives). For the control experiment, precision was 0.86 ?0.13 and for the hybrid scheme 0.83 ?0.18.

DISCUSSION AND CONCLUSIONS

The sequential operation of two BCIs with different mental strategies (foot motor imagery and spatial visual attention) represents one realization of a hybrid BCI. Only 2 EEG channels (one bipolar recording at O1 and a Laplacian EEG channel at Cz) are needed for control of this hybrid BCI application. Reduced number of EEG channels is important for applications in field settings such as at home, hospitals, offices, or in outer space. The hybrid BCI resulted in a lower number of false positives (less than 50%) than with the SSVEP-based BCI alone. The majority of participants succeeded in operating the self-paced hybrid BCI with a good performance [1]. Both, the orthosis and the brain switch, are self-paced and include visual feedback. This means that both types of BCIs fulfill the requirements of a BCI, namely non-muscular control, extraction of specific brain signal features that reflect the user's intention, real time processing and feedback. The SSVEP-based orthosis system introduced here can be seen as benchmark application suitable to investigate, test and develop different brain switch designs in real time applications with feedback. Such a benchmark is not only helpful to further improvement of the EEG-based brain switch, but also to develop new brain switch concepts. One such concept could be the detection of imagery induced (de)oxyhemoglobin changes measured with the near-infrared spectroscopy (NIRS) [2].

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SUPPORT

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KEYWORDS

Brain-computer interface, hybrid BCI, motor imagery, spatial visual attention, event-related desynchronization, SSVEP BCI, ERD BCI

L-1 Event Related Potential Classification "Best Practice"

Jason Farquhar*, Jeremy Hill

Background and Objective

Event Related Potentials (ERPs) are signals which are time-locked to some external stimulus with a prototypical temporal and spatial distribution, e.g. a positive peak after 300ms centered over electrode CPz. Such signals form the basis of may successful evoked response Brain Computer Interface (BCI) systems such as the Farwell and Donchin Visual speller [1] or the SSEP. To maximise BCI system performance one wants to identify an ERP as reliably as possible in the least possible time, ideally after only a single presentation. Thus, the BCI problem is essentially one of classification -- does the recorded [d x T] spatio-temporal signal contain the target ERP or not? There is a vast literature in the machine-learning community on how to best learn such a classifier and many different algorithms have been tried for ERP classification, e.g. LDA, SWLDA, SVM, LR. However, there is also a general sentiment in the BCI community that the actual classifier used doesn't matter so long as the data is pre-processed correctly, see [2]. The rest of this paper is partly an investigation of this claim to see if the classifier does matter, and partly an empirical study into what is the best combination of pre-processing and classifier training required to maximise final ERP classification performance.

Methods

The ERP classification process generally consists of 3 steps; 1) Spectral filtering, to a frequency range of interest 2) Spatial filtering, where sensors are linearly re-weighted to give new 'virtual sensors'. 3) Classifier training: To investigate each steps importance they were systematically varied and the effect on ERP classification performance assessed in an off-line study, using a large (>120) database of visual, auditory and tactile ERP classification problems.

Results

The main results of this analysis are; 1) With a "low number" of detectors and "perfect" pre-processing the type of classifier doesn't matter. 2) In "all other" cases regularised classifiers perform significantly better. 3) Spatial whitening (a simple form of spatial-filtering) further improves performance but "only" when used with a regularised classifier.

Conclusions

ERP classification is important for the performance of many evoked response BCIs. This study has used a large scale systematic study to develop an ERP classification best-practice. Specifically you should; 1) Use as many detectors as practically reasonable 2) Roughly spectrally filter you data 3) Spatially filter your data using spatial whitening 4) Use a regularised classifier training method. In this way you can be sure that you obtain the best possible ERP classification performance.

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Support

This research is funded by the Dutch BrainGain SmartMix project. Keywords: Event Related Potentials, Spatial Filtering, Regularisation, Classification

L-10 Initial design of an AAC device with non-invasive BCI, adaptive language modeling and Rapid Serial Visual Presentation (RSVP)

Deniz Erdogmus*, Kenneth Hild II, Barry Oken, Brian Roark, Melanie Fried-Oken

Background and Objective

We are designing a portable communication device that relies on a non-invasive BCI with optimized language modeling for literate individuals who are functionally locked-in. We use single trial P3 detection for binary selection of single characters in a rapid serial visual presentation (RSVP). Our RSVP system prototype uses an N-gram character-based language model, which is an (N-1)-order Markov process, to order symbols in real-time. Letters and characters appear sequentially using the order specified by the language model, the output of which is based on the string of previously detected symbols. A subset of the symbols is repeated at the end of a given sequence based on (1) a limited number of symbols having a high, but sub-threshold, posterior probability and (2) a flag from the vigilance detector indicating that the specified letter was likely not attended. In this paper, we present preliminary results for target classification in such an RSVP paradigm.

Methods

We use a quadcore laptop, each core operating at 2.53GHz. The software uses Labview (National Instruments, Austin, TX), executing functions written in Matlab (Mathworks, Natick, MA) and C, exploiting multicore capabilities. EEG and trigger data are acquired using g.USBamp (Guger Technologies, Austria), a 24-bit, 16-channel biosignal amplifier sampled at 256Hz through a USB2.0 connection. Rapid and accurate stimulus presentation capabilities of the Psychophysics Toolbox v3 (PTB-3; http://psychtoolbox.org) are utilized by presenting a string of symbols on the subject screen in synchrony with the vertical retrace of the 60Hz, LCD monitor using OpenGL commands embedded in PTB-3, while EEG activity is monitored on the administrator screen. For this report, 30 symbols (26 letters and 4 editing characters) appear one at a time using a serial visual presentation paradigm. Synchronization of the different processes is guaranteed by having each process record timestamps from the same high-precision 64-bit hardware counter, which updates at the processor rate. For data collection, one able-bodied, literate adult matched visually presented symbols to ones that appeared in the series. Rare target letters and common non-target letters (white symbols on black background) and rare non-targets (different color) were presented for 500 ms each, with 80 ms black inter-stimulus intervals. Recording was done from 19 10-20 system scalp locations and non-cerebral activity including EOG. To detect symbol selection intent, we used a Support Vector Machine classifier which attempts to detect the P3b event-related potentials from single-trial data.

Results

Using a Gaussian kernel SVM to assess 10-fold averaged AUC, results were targets vs. non-targets (common and rare non-targets), AUC=0.9891; target vs. common non-targets, AUC=0.9874; and rare non-target vs. common non-targets, AUC=0.9874.

Discussion and Conclusions

Our initial experiment indicates that there might not be statistically significant differences in BCIs based on P3a or P3b phases. The artifact removal process is continuously trained in a supervised fashion. The classifier is initialized using training data previously recorded from the user and is updated periodically using decision feedback. In the future, we will incorporate a vigilance detector, based on the number of eye blinks and the instantaneous power of alpha waves. Unique design of the RSVP system will be discussed.

Support

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Keywords

Noninvasive BCI; language modeling; single P300 signal detection; rapid serial visual presentation

L-11 P300-BCI: Disassociating Flash Groups from Physical Organizations Provides Improved Performance

George Townsend*, Jessica Shanahan, Gerald Frye

Background and Objectives

Since its inception, the P300-based BCI has typically flashed in rows and columns [1]. Recently, the “checkerboard?(CB) paradigm was introduced in which targets are grouped in rows and columns on two “virtual matrices?taken from the white and black squares of a checkerboard overlaid on the physical matrix [2]. Disassociating the physical rows and columns of the matrix from how they are grouped to flash brings advantages by: 1) avoiding the problematic effects of double target flashes [3], and 2) not allowing adjacent targets to flash together. In this study, this disassociation of the “flash groups?from the physical matrix is taken further. The flash groups become purely “abstract?bearing no relationship to rows or columns either physical or virtual. This study compares performance of this new paradigm named ?-Flash?(5F) to the CB.

Methods

Rather than arranging targets into flash groups based on physical constraints or organizations, constraints designed to maximize the performance of the P300-BCI guide this process. These “performance based?constraints are as follows: limit the total flashes required to present and uniquely identify all items (one sequence), minimize the number of items that flash in common with other items, ensure a minimum time between consecutive flashes of any given item, and provide the most number of flashes possible of each target within each sequence. Using an 8x9 matrix, 36 flashes per sequence are necessary to meet these constraints, during which each matrix item flashes five times. At most, two flashes of any item are in common with another item, requiring only three good P300 responses to uniquely identify each target. By contrast, other paradigms present fewer flashes of each target and require that all target flashes be recognized to identify the attended target. For example, the CB presents only two flashes of each item requiring both to be recognized. The 5F ensures that adequate time will elapse between consecutive flashes of a given item. In this study, each group flashed for 62.5ms with 62.5ms between flashes. In each session, a no-feedback calibration phase is followed by an online phase providing feedback to the subject. The 5F and CB sessions were counter-balanced.

Results

Preliminary results show that 5F improves speed and accuracy over the CB (which is superior to the standard “row-column?paradigm). Although 50% more flashes (36 in total) are required to sequence through all items than in a CB sequence, each item flashes five times. Thus, three additional opportunities exist per sequence to record good P300 responses for the attended item. For example, two F5 sequences take the same amount of time as three CB sequences, however 67% more targets flashes appear.

Discussion and Conclusions

This new paradigm addresses paradigmatic problems with the traditional row/column approach and simultaneously combines solutions by focusing on organizing the “flash groups?to avoid the problems altogether. As with the original CB paradigm, adjacency distraction is reduced and double flashes are eliminated, while more subtle shortcomings of the CB are addressed by the 5F.

Support

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Keywords

BCI; P300 event-related potential; amyotrophic lateral sclerosis; EEG

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L-12 An Open-Access P300 Speller Database

Claudia Ledesma-Ramirez, Erik Bojorges-Valdez, Oscar Yanez-Suarez*, Carolina Saavedra, Laurent Bougrain, Gerardo Gentiletti

Background and Objective

The P300 speller [1] is one of the most well-known applications in Brain-Computer Interface (BCI). This application has potentially a strong impact for patients with motor disabilities given its high rate of accuracy and reasonable speed. Many improvements over the pioneering systems have been done and some comparisons exist [2]. To contribute to this process, we propose an open access to a large database obtained from first-time users of the 6x6 P300 speller application in BCI2000 [3]. We also propose a set of Matlab functions to prepare data for the classifier. Some documented and objective performance measures and first results for comparison are also available. Database The Neuroimaging Laboratory at UAM recorded 30 healthly subjects (18 Males/12 Females, age 21-25) controlling various conditions (sleep duration, drugs, etc). Each subject participated to 4 sessions with 15 sequences: 1) Three copy-spelling runs 2) One copy-spelling run with feedback using a classifier trained on data from session 1 3) Three free-spelling runs (desired words, around 15 characters per subject) 4) Variable free-spelling runs with reduced number of sequences given by the classical highest bit-rate analysis. 10 channels (Fz, C3, Cz, C4, P3, Pz, P4, PO7, PO8, Oz) have been recorded using the g.tec gUSBamp with sampling rate of 256Hz, a right ear reference and a right mastoid ground. An 8th order bandpass filter, 0.1-60 Hz and a 60 Hz Notch have been used. The stimulus is highlighted for 62.5 ms with an inter-stimuli interval of 125 ms. We also propose a set of Matlab functions to extract and average target and non-target responses specifying for example the number of sequences to average and the duration of the response and to save it in Matlab or ASCII format. The database, a complete description of the parameters used for the speller and the code are available at:

http://akimpech.izt.uam.mx/dokuwiki/doku.php. Analysis SWLDA classi?ers have been trained for each subject. We used an objective, comparable measure of performance taking into account for the choice of feature set and independent of training/testing set. Indeed, the relative (receiver) operating characteristic or ROC curve re?ects intrinsic class separability and can be summarized by the area under the ROC curve, Az. Higher values of Az correspond to better classifiers.

Results

As a reference, results for each subject are available on the web site. Accuracy using SWLDA with 15 training sequences can be established in terms of an 86.7% of the participants having 100% correct spelling, while the lowest percentage of correct detected characters reached by the rest of the population was 85%. ROC areas above 0.95 were reached by 76.7% of the population in about 10 sequences. Thus, for 15 sequences the general performance is very good and confirms the quality of the database. Classifier features were selected mainly from P08, Oz, PO7 and Pz electrodes and within the 100-290 ms. This shows that EP related to visual stimulation and its recognition play an important role in the high accuracy of the classifier.

Discussion and Conclusions

This open-access P300 database includes recordings from 30 healthy subjects. Data is available in BCI2000 and Matlab formats. A set of Matlab functions allows you to extract the information you need from data. We hope the work will contribute to better compare classifier techniques.

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L-13 Effective Classification and Interpretability of ERP Components using Shrinkage Linear Discriminant Analysis

Benjamin Blankertz*, Stefan Haufe, Anne Porbadnigk, Matthias Treder

BACKGROUND AND OBJECTIVE

Analyzing brain states that correspond to event related potentials (ERPs) on a single trial basis is a hard problem due to the high trial-to-trial variability and the unfavorable ratio between signal (ERP) and noise (other brain activity). Here, we present a framework for decoding and interpreting ERPs based on linear discriminant analysis (LDA) with automatic shrinkage of the covariance matrix (Shrinkage-LDA).

METHODS

Data of a Matrix Speller study with 13 naïve participants was used to evaluate ERP classification performance of the proposed method and to demonstrate the interpretability of what has been learnt by the classifier from the data of individual subjects. The analytical solution of the optimal shrinkage parameter to improve the estimation of the empirical covariance was calculated according to [1] and used in the setting of ERP classification.

RESULTS

Shrinkage-LDA provides a tremendous increase in classification performance compared to LDA for higher dimensional features as required in attention-based BCI spelling devices. Applied to the Matrix Speller data, Shrinkage-LDA performed superior to Stepwise-LDA which is considered the current state-of-the-art. The advantage of Shrinkage-LDA was most prominent in simulations with a small number of repeated intensifications, i.e., in cases of an unfavorable ratio of dimensionality of features and number of training samples.

DISCUSSION AND CONCLUSIONS

Shrinkage-LDA is a comparably simple classification method which does not require any hyperparameters to be selected. The linear shrinkage factor that is determined according to an analytical solution controls the trade-off between goodness-of-fit and model complexity. This is directly related to a morphing between a difference pattern of ERPs and a spatial filter which cancels non task-related activity. The solution can be visualized intuitively as scalp topographies and provides insight in the spatial structure of interfering noise, which may be useful to improve preprocessing, feature extraction and experimental design. By the selection of appropriate target matrices in the shrinkage procedure, apriori knowledge can be included, and invariances that can be characterized as subspaces of the feature space can be enforced in the classifier.

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Keywords

EEG, Event-Related Potentials, Linear Classification, Shrinkage, Interpretability, Matrix Speller

L-14 Optimized Stimulus Design for a Spatial Auditory BCI based on ERP

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Background and Objective

Late ALS stages result in unreliable eye control and increased secondary vision problems. In order to provide a remedy for these patients, a new spatial auditory BCI design was recently introduced [1] which is based on ERP components. As ERP effects are known to be susceptible to changes of the experimental design, this offline study explores the influence of the variables loudness, stimulus duration and inter stimulus onset (ISO) to optimize them under real-world conditions for an online study with patients.

Methods

Given written consent, healthy subjects were seated in the center of a ring of 6 speakers. During a sequence of 60 or 66 tones from different directions, a subject's task was to count the 10 (11) target tones (defined by direction and pitch) and ignore the non-target tones. EEG was recorded via 64 electrodes in an office room. A sequence realized either one out of seven loudness levels, from very quiet but above hearing threshold (52 dB) to loud (74.5 dB), during 1000ms ISO (block 1) or 300ms ISO (block 2), or one out of six stimulus durations (5ms to 300ms), again in two ISO steps. At the time of submission, seven subjects were recorded with varying duration and six for varying loudness. The design was pseudo-randomized in the levels of the respective variable and 6 target directions. Changes in the ISO were applied blockwise during 2 blocks of at least 5000 tones each. It was ensured that successive stimulations from the same direction were separated by at least two stimuli from a different direction. To analyze the EEG data, a band pass filter in the range of [0.2Hz, 40Hz] was applied and outliers were removed (based on a fixed variance criterion). Then time windows (-50ms to 800ms around single stimuli) were cut out and baselined in the 50ms pre-stimulus interval. Binary target/non-target classification of single stimuli was performed with regularized FDA. Classification errors were estimated based on cross validation.

Results

The described experimental procedure resulted in the desired enhanced ERP effects for target stimuli. Depending on the subject, an attention-modulated enhancement of early negative component around 140ms could be observed in addition to or instead of an enhanced P3 component. While individuals had p references for low-to-medium loudness levels, grand-average analysis of classification errors did not reveal an optimal loudness for neither 1000ms nor 300ms ISO. However, results show increased inter-subject variance for higher loudness levels. Individual p references

for stimulation duration were not so clear, but the grand average classification error suggested the use of approximately 40ms duration within the used setup for both ISO settings.

Discussion and Conclusions

The relatively slow setup of 1000ms or 300ms ISO (compared to [1]) reflects the necessities posed by the work with patients. Previously reported systematic increase in ERP amplitudes upon louder stimuli [2] could not be verified for the special case of the new spatial auditory BCI paradigm, such that the amplitude can be chosen according to the liking of the subject. Individual low classification rates for loud stimuli might be caused by irritations due to stronger sound reflections in the room. The clear optimum for medium-length stimuli is stable over ISO conditions and a useful starting point for individual optimization.

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L-15 Preliminary study towards a multi-modality P300-based speller.

Vaishnavi Karnad*, Ding-Yu Fei, Ou Bai

Background and Objective:

The aim of this study was to compare the multi-modality effects on event-related potentials of P300 with a view to find a computational model for P300 Speller that would provide faster and more accurate communication.

Method

The procedure was run for four normal volunteers. The visual two-stimulus oddball paradigm with a row-column 4x4 matrix of letters was used. A row or column was randomly flashed. The subjects were asked to determine whether the stimulus contained the required letter or not, thus defining it as target or non-target stimulus. Three runs of data were collected per subject with different tasks after identifying target stimuli. In the first run the subjects were asked to count the number of flashes of the target stimulus. For the second task subjects were asked to flick their right wrist instantly on perceiving the target stimulus. In the third run, the subjects were told to sustain the urge of flicking their right hand by motor imagery until the next stimulus was perceived. The EEG was recorded from 10 channels according to the international 10?0 system. The signals in the duration window of 0.1ms before the stimulus to 0.85ms after the stimulus were extracted by ensemble averaging for analysis. The features of P300 used as criteria were its latency and peak to peak amplitude of P300 potentials.

Results

The preliminary data collected showed that the amplitude of the P300 signal over the channels CZ, CZP and PZ varied as 0.81uV, 0.54uV and 0.3uV when the task was to count. This value is that of peak to peak amplitude for target-case minus that for non-target case. However in case of motor imagery, the same channels showed an increase in amplitude giving values 1.13uV, 1.47uV and 1.14uV. The latency of the P300 peak was between 300 and 450ms after stimulus. This value was subject dependent but not task dependent. The results were same for three out of four volunteers investigated.

Discussion and Conclusions

The three tasks involved the standard P300 alone, P300 with partial movement-related cortical potentials and P300 with contingent negative variation respectively. The results showed that the involvement of motor activities enhances the P300 amplitude. The addition of motor imagery caused a two fold increase in the amplitude. Thus the increase in SNR gave more accurate results . Also the latency remained undisturbed. Hence it is possible to develop a faster and more accurate algorithm for P300-based Speller based on a combination of P300 along with motor imagery. The next steps to this study are to develop an algorithm for a P300-based speller using multi-modality as its basis. More datasets will also be collected to support the current results .

L-16 Toward the optimization of P300-based BCI protocols: decimation factors and classifiers

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Background and Objective

The aim of this study is to provide some initial guidelines for relevant parameters selection to set up P300-based BCI systems. The ultimate goal will be to optimize system performances. Data were analyzed with 7 classifiers and 4 decimation factors (DFs); these latter were taken into account to consider the influence of the dimensionality of the training dataset. Classification results were compared in term of mean Expected Selection Cost (ESC) [1], that is the number of logical trials (flashes) needed to generate a correct symbol, taking into account the errors and abstentions and the strategy to recover them. The ESC of a system should be as low as possible to maximize the efficiency of the system.

Methods

Ten subjects participated to a 6x6 speller based P300 experiment (61 EEG electrodes), such as in [2-3]. Three artifact-free sessions (6 characters each) were used for classifier training and 3 for the classification. Five electrodes and 600 ms duration time interval, after each stimulation, were selected. 10 flashes for each of the rows and columns of the matrix were used for the classification. The 7 classifiers were: Stepwise, Fisher, Bayesian and Regularized Linear Discriminant Analysis (SWLDA, FLDA, BLDA, RLDA),

Support

Vector Machine with linear and RBF kernels (L-SVM and RBF-SVM) and Artificial Neural Networks (ANN). The selected DFs were 1 (no decimation), 2, 4, 8 and 16; decimation was preceded by a moving average filtering of the data. All the classifiers were fed with the same dataset in order to attain a reliable comparison. The P3Classifier from the NPXLab suite (www.brainterface.com) was used for the analysis.

Results

Classifications results obtained from all subjects were averaged and showed that RLDA and BLDA achieved the lowest ESCs. In fact, when they are compared to SWLDA (ESC=1.48), the most used classifier for P300, they required respectively on average 23% (ESC=1.25) and 15% (ESC=1.33) less trials to generate a correct character. Non linear classifiers, RBF-SVM and ANN, are the most “selections-demanding? while L-SVM and FLDA achieved ESCs in middle of the range. DF considerably affected the performances of FLDA and ANN: with no decimation, the FLDA’s ESC did not converge (too many errors!) and for the ANN it was equal to 1.82. The increase of the DF yielded to an ESCs decrease. SVM-RBF’s ESC increased with the increasing of the DF. BLDA and RLDA both had a minimum ESC when the DF was equal to 8. Finally, in the best condition the SWLDA (DF=16) was characterized by an ESC=1.35 while RLDA (DF=8) had an ESC=1.19, thus indicating that RLDA provides for a 15% faster communication rate.

Discussion and Conclusions

Optimization of P300-based BCI systems performances requires different parameters to be considered. According to the present findings, obtained by comparing different classifiers and decimation factors in terms of number of selections needed to generate correct symbols, the combination that maximizes system efficiency is RLDA with DF=8. Other parameters, such as channels sets, filtering settings, time intervals and number of trials, are currently under investigation.

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Keywords

BCI, P300, Optimization, P3Classifier.

L-17 A Brute Force Investigation of Electrode Subsets for a P300 BCI

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Michael T. McCann, David E. Thompson, Jane E. Huggins Department of Biomedical Engineering, Department of Physical Medicine and Rehabilitation, University of Michigan Keywords: BCI, P300, EEG Background and Objective

The cost and setup time of P300 BCIs are strongly linked to the number of electrodes used. It is therefore advantageous to use the fewest electrodes necessary to achieve the desired accuracy. P300

BCIs have used a single electrode [1], or caps with 64 or more electrodes. Previous work has compared a small number of different electrode sets [2]. The current work compares all possible subsets of electrodes given a specific 16-electrode cap. Sets of 8 electrodes or fewer are of special interest because they allow a switch from 16-channel amplifiers to less-expensive 8-channel amplifiers.

Methods

Over three sessions, 12 able-bodied subjects completed an initial 19-character training run (with no feedback given to the user) and then 9 copy-spelling runs of 23 characters each (with feedback and correction, subjects typed an average of 32.5 ?11.3 characters/run). All sessions were conducted using a 16-channel EEG cap (F3, Fz, F4, T7, C3, Cz, C4, T8, CP3, CP4, P3, Pz, P4, PO7, PO8, and Oz). The method of least squares (LS, as implemented by the P300GUI utility in BCI2000) was used to generate a set of linear classifier weights from the initial run. These weights were used to give feedback in the subsequent runs. See [3] for further detail. Offline, LS and stepwise linear discriminant analysis (SWLDA) were applied to the initial training data to generate unique weights for every possible subset of the 16 electrodes used. The resulting 65,535 sets of weights for each of LS and SWLDA were tested on the remaining 9 runs. Accuracy was the number of correctly typed characters divided by the total number of typed characters. The best set for each set size was the set with the highest accuracy averaged over all subjects. Leave-one-out cross-validation was performed for each electrode set size to estimate generalization to new subjects.

Results

Mean accuracy for the 16-electrode set was 81.6 ?16.6% (average ?standard deviation, SWLDA) and 82.1 ?17.6% (LS). For 8-electrode sets, cross-validation implies a 0.2 ?18.4% drop in accuracy for SWLDA and a 1.2 ?20.0% drop in accuracy for LS. For both methods , there was a smaller than 1% drop in accuracy for 9 of 12 subjects. Using SWLDA, the best set of 8 electrodes was T7, C2, CZ, CP4, Pz, PO7, PO8, and Oz, with an average accuracy of 82.8 ?16.7%. Using LS, the best set of 8 electrodes was F3, T7, C3, CP4, Pz, PO7, PO8, and Oz, with an average accuracy of 83.1 ?16.9%. For both methods , a single set of four electrodes (Pz, PO7, PO8, and Oz) could provide acceptable (>75%) accuracy for 9 of 12 subjects.

Discussions and Conclusions

This study presents a brute force method for selecting electrodes subsets for a P300 BCI. Using fewer electrodes offers an attractive reduction in equipment cost and setup time. Future studies will apply this technique to subjects with a specific motor disability (e.g. amyotrophic lateral sclerosis) to identify good electrode sets for that population.

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L-18 EEG features correlated with performance in P300-based BCI operation: a long-term case study in a home user with amyotrophic lateral sclerosis (ALS)

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Background and Objective

Brain-computer interface (BCI) technology holds promise to restore the communication and control ability of individuals with severe motor disabilities (Wolpaw et al. 2002). An EEG-based BCI system that detects the P300 event-related potential (ERP) allows users to select items from a matrix consisting of letters, numbers, and function calls (after the method of Donchin et al., 2000) using brain signals rather than the brain's normal output pathways of peripheral nerves and muscles. Our laboratory seeks to realize independent home use of P300-based BCI by severely disabled individuals. In an earlier study, we found that P300-based BCI performance (i.e., accurate classification) on test data was correlated with the test data and was not correlated with the training data (Mak et al. 2009). The present study set out to identify EEG features that correlate with P300-based BCI performance in the first long-term home user, a man severely disabled by amyotrophic lateral sclerosis (ALS).

Methods

The BCI user is a 51 year-old man with ALS whose only remaining muscle control consists of weak eye-movements. He uses the BCI up to 6-8 hr/day to communicate with family and friends and to supervise his medical research laboratory. Our P300-based BCI methodology is fully described in (Krusienski et al., 2008). We analyzed data from 155 copy-spelling sessions over 12 months (18 letters per session; mean session accuracy = 79(?2SD)%; chance accuracy = 1.4%). For each of the 8 central and posterior EEG channels, we extracted frequency-domain and time-domain features and then performed stepwise multiple linear regression analyses to determine which features correlated with accuracy.

Results

We identified seven EEG features that were significantly correlated with accuracy ($R^2=0.511$, $P<0.001$): 4.5-8 Hz (i.e., theta) power at Cz; peak-to-peak amplitude of the response to the target item at Cz, P4, and Oz; and peak, peak-to-peak, and root-mean-square amplitude of the responses to non-target items at P4.

Discussion and Conclusions

These results suggest that P300-based BCI performance might be improved by: (1) using theta power at Cz to assess online the reliability of concurrent responses; (2) modifying stimulus presentation parameters (e.g., matrix size, matrix intensity, stimulus rate, etc.) so as to optimize one or more of these features; and/or (3) developing user training methods that optimize one or more of these features. Such user-specific improvements might substantially increase the capacity and reliability of P300-based BCI systems for long-term home use by people with severe disabilities.

Support

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Keywords

BCI; ALS; Event-related potentials; rehabilitation; communication

L-19 Toward Independent Home Use of a P300-BCI: An Email Application

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Background and Objectives

Brain-computer interface (BCI) technology allows individuals with severe motor disabilities to regain communication and control functions. Recent developments in P300-based BCI research provide assistive communication ranging from simple yes/no selection (Sellers and Donchin 2006) to text-spelling matrices (Farwell and Donchin 1988, Donchin et al. 2000) that allow word processing and personal communication. These advances need to be translated into practical applications that enable BCI users to participate at a community level. In response to this need, we have developed an Email Client (EC) application for the P300-based BCI speller (Krusienski et al. 2008). This study evaluates the practicality and performance of the EC as a communication tool and details a protocol that trains new users in a step-by-step manner. We are also extending this training protocol to BCI home users using remote technology with an internet server and web camera.

Methods

Prospective BCI EC users follow a protocol consisting of three phases: a calibration phase of copy spelling (A); a word processing (WP) phase (B); and an Email Client (EC) phase (C). In phase A, 70 character-selection trials are gathered with the standard 6x6 matrix for system calibration. If users attain a mean accuracy of at least 75% (chance accuracy 2.8%), they proceed to phase B. In phase B, they free-spell using an 8x9 matrix (chance accuracy 1.4%). If accuracy is =75% , they continue to phase C. In phase C, the users are guided through a series of exercises with the 8x9 matrix that teach them to write and send email messages independently.

Results

To date, four users without disabilities have undertaken the protocol. They copy-spelled in phase A on the 6x6 matrix at a rate of 1.7 characters/min, with online and offline accuracies of 85-100% and 97-100% respectively. All four proceeded to phase B and free-spelled on the 8x9 matrix with online accuracies of 90-100%. Finally, they all proceeded to phase C in which they used the EC to write and send emails on the 8x9 matrix with online rates of 1.4-2.4 characters/min and online accuracies of 82-100%. We also conducted this protocol remotely via the internet with one home user with amyotrophic lateral sclerosis (ALS). After completing the protocol, she was able to send emails independently with an online rate of 2 characters/min and online accuracy of 84%. Discussions and Conclusions These initial results indicate that a protocol comprising a series of guided exercises can enable new BCI users to achieve independent use of an Email Client for the P300-based BCI speller. With further confirmation in home users, this new BCI application should be able to help individuals who are home-bound by severe disabilities to interact with others and participate in their wider personal and professional communities.

Keywords

BCI; ALS; email; rehabilitation; communication

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L-2 Stimulus Presentation Manipulations in P300-BCI: Flashing Stimuli are not Necessary for Accurate Spelling

Eric Sellers*, Stephany Mesa G

Background and Objectives

The EEG-based P300-BCI can provide independent communication for people locked-in by ALS[1,2]. The P300-BCI requires little training[3], and speed and accuracy are relatively high as compared to other BCI systems. Nonetheless, a major drawback of BCI technology is slow communication rate. Most P300-BCI studies focus on signal processing methods to improve speed and accuracy. A less explored method to improving P300-BCI is designing new presentation paradigms (e.g.,4,5). Townsed et.al[2] described the "checkerboard?(CB) paradigm that flashes quasi-random groups of items instead of the typical row/column paradigm. Their results showed significant improvement over the row/column and suggest that paradigm manipulations are a relatively unexplored area where much progress in performance can be made. The current study uses the CB paradigm and compares flashing from gray to white, to a condition that changes from gray to black, the "blink?(BL) condition.

Methods

Six subjects have completed the study. None had prior BCI experience. All subjects performed a session in the CB condition and a session in the BL condition, counter-balanced. Using an 8x9 matrix of alphanumeric characters, function keys, and commands, the subjects?task was to copy-spell 36 items by focusing attention to a predefined matrix item and count the number of times it flashed (or blinked). Each session began with a no-feedback calibration phase to serve as training data for a SWLDA[6] classifier that would present online feedback during the copy-spelling task. During calibration 120 flashes were used for each item selection (10 targets). To optimize the number of flashes for the online copy-spelling task the Written Symbol Rate (WSR)[7] was used. The WSR calculates the number of flashes necessary to obtain the highest number of selections/min for each subject and each condition. Matrix items were presented in quasi-random groups of six every 125ms. The copy-spelling task was identical to the calibration phase with the exception that accuracy feedback was presented after each item selection.

Results

Preliminary results suggest that CB accuracy is higher than BL accuracy (88.9% and 82.4%). Accordingly, the theoretical bit rate (bit rate calculated without the time between selections included) is higher for the CB than the BL (30.6 bits/min and 25.6 bits/min). Several differences in waveform morphology are present. P300 latency at locations Cz and Pz is earlier in CB than in BL (approximately 230ms and 290ms) and amplitude of the negative peaks between 400-600ms is higher in CB than in BL (approximately -3.7µV and approximately -2.9µV). Electrode locations PO7 and PO8 are more negative between 160-240ms in BL than in CB (approximately -0.85 µV and 0.45 µV). Four of the six subjects preferred the BL, one had no preference. Eighteen to 24 additional subjects will complete the experiment.

Discussion and Conclusions

The CB results reported here replicate those reported by Townsend et al.,[2] and show that a condition that extinguishes, or blinks, stimuli produces similar results . Although CB accuracy is higher than BL, more subjects preferred the BL and reported less eye fatigue. These results suggest that blinking stimuli may be a more viable option for long-term use and should be replicated in a study that requires several hours of BCI use.

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Keywords

BCI; P300 event-related potential; amyotrophic lateral sclerosis; EEG

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L-20 Overlaid P300 stimulation-based BCI: a solution to “limit?workload in communication application?

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BACKGROUND AND OBJECTIVE

Advancing in BCI technology towards practical applications in technology based assistive solutions for people with disabilities requires coping with problems of accessibility and usability, in order to increase user acceptance and satisfaction. Here, we propose an initial approach in the assessment of BCI technology development in terms of usability that is focused on the reduction of user's mental workload in operating a mainstream software controlled via a P300-based BCI. In this study, we compare workload under two conditions: a) using separate screens/windows to display the control interface (i.e. P300 stimulator) and the application [1]; b) using a prototype with an overlaid interface. This latter condition should require the user not to switch attention as in the case of two separate screens/windows, and thus would reduce her/his workload in mastering the BCI application.

METHODS

User interface. The prototype (described in [2]) is based on a brain transducer based on P300, implemented in the BCI2000 platform [3], and on the QualiWorld accessibility software (QualiLife SA, Paradiso, Switzerland). No dedicated BCI window is visible to the user [3] in condition (b). Experimental procedure. In a preliminary testing phase, 2 subjects were challenged with 3 tasks (internet browsing; word processing configuration of the software), each requiring 7-9 selections with both overlaid and split interface. In the latter case, a second screen prompted the same icons available in the application interface, arranged in a matrix. Behavioral assessment. Rating of mental workload was performed by means of the multidimensional NASA TLX questionnaire [4] that assesses the workload by considering six different factors: Mental, Physical and Temporal Demands, Frustration, Effort and Performance. These factors have a direct bearing on the usability of a software interface. If fewer mental resources are used, then the efficiency, effectiveness and satisfaction associated with the interface can be increased. The questionnaire was self-administered to both users at the end of each performed task to capture the potential differences in workload level relative to the 2 conditions.

RESULTS

Using the overlaid interface, the average time for each selection (14sec) was remarkably lower with respect to the split interface (23sec). The workload assessment indicated that the overlaid interface was associated with a lower overall mental workload (average score for overlaid interface=33.3, for split interface=74.7). The score of each single NASA TLX dimension was always lower for the overlaid interface except for the temporal demand, in both subjects. DISCUSSION and CONCLUSION The proposed prototype extends the concept of P300 selection from letters or menu items from an own interface to the more flexible concept of integrating with the external software interface. We expect this approach to improve the interface usability; the NASA TLX is a promising tool in the assessment of BCI technology within the framework of a user centred evaluation methodology.

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Keyword

Mental Workload, BCI, Usability, NASA TLX, P300.

L-21 A multimodal (visual+auditory) speller

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Background and Objective

Brain Computer Interfaces can help people with severe disabilities to communicate by means of measured electrical signals from the brain. The classic visual speller [1] works by interpreting the P300 ERP component from EEG recordings using visual stimulus presentation of flashing rows and columns from a letter matrix on screen. In patients with neurodegenerative diseases muscular control of the eyes may be impaired or deteriorate with time, so using non-visual, e.g. auditory, stimulation can present a valid alternative. A major difficulty in the P300 auditory interface is increasing the throughput rate to match typical P300 visual spellers. Previous work [2,3] states that it may be possible to increase the throughput of a P300 auditory interface and using a multimodal interface could be of benefit. The above issues and findings lead us to formulate two principal goals for this study. First, we want to identify how auditory stimulation can be used to reliably elicit ERP components in combination with fast stimulus presentation comparable to P300 visual spellers (e.g. 5Hz). In order to achieve high accuracy at high stimulus presentation speed we experiment with different auditory stimulus configurations. The second goal is to investigate whether a multimodal interface simultaneously combining visual and auditory stimuli at a high presentation speed can improve performance of a P300 speller.

Methods

A row column letter matrix design is used for the visual stimulation [1]. In the auditory case we experiment with different sounds that represent rows and columns of the letter matrix, such as spoken first letters of the columns (a b c d e f) and rows (a g m s y). For better discrimination a female and a male voices are used for the rows and columns respectively. We also measure if encoding the sounds spatially relating to the visual position of a row/column can be of help in discriminating the sounds at fast presentation rates. In the multimodal setup both sounds and flashes are presented to the subject with varying the onsets to account for processing differences between the sensory areas. The data analysis is using the standard P300 speller pipeline, that is by bandpassing the data and applying a regularized linear classifier.

Results

Our initial tests show that auditory discrimination is indeed feasible at the rate of 5 auditory stimuli per second and can be used in combination with the visual paradigm. EEG experiments are on the way.

Discussion and Conclusions

The development of a multimodal interface could increase the reliability of the speller. A multimodal setup could also help patients with deteriorating vision to adapt to the auditory interface by slowly removing the visual domain in the progress of training. A further benefit of using several modalities can be the increased flexibility for patients that could communicate in one modality while being able to attend to the other. For example, one could look at a received email whilst writing a response via the auditory interface.

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Support

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Keywords

(maximum of 6) P300 speller, multimodal, auditory, high-throughput

L-22 Using BCIs to explore brain function: EEG/MEG classification maps in a classical P300 speller

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Background and Objective

The aim of this study was to exploit BCI classifiers in order to define the topography (i.e. brain areas) and components of the event-related potentials generated in a typical P300 spelling application. In this widely used BCI application an alphabet of symbols, disposed on a squared matrix, is displayed on a PC screen and the subject is asked to gaze upon one of the symbols. Afterwards all the rows and columns of the matrix begin to flash in a random order. Because evoked responses to target (flashing) and non-target (non flashing) stimuli are expected to have different spatial distribution, it could be deduced, by means of a classifier, which symbol the subjects are fixating. On the other side, it could also be assumed that a classifier performs better when the difference of the target and non-target responses is higher. By deduction, classification accuracy could represent an indirect measure of brain processing workload.

Methods

Six subjects participated to a 6x6 speller P300 experiment such as in [1]. Data were acquired by means of either an EEG system (61 sensors; 3 subjects) or a MEG system (274 sensors; 3 subjects). Inter Trial Interval (ITI) was set to 1000 ms to minimize the effect of responses overlapping. Subjects were asked to fixate one symbols communicated by an operator (15 flashes for each row and column, 36 symbols for the EEG and 18 for the MEG). Responses evoked during the fixation of six symbols randomly chosen were then to train the classifier (SWLDA) while the remaining were used for classification. This procedure was repeated in order to have 1080 classifications performed independently for each sensor and for 8 overlapping time intervals of 200 ms duration that started from trigger onset and were increased by 100 ms step. A total of 527040 and 2367360 classifications were performed for each of the EEG and MEG data respectively. The classification accuracy was computed for each of these configurations, leading to 61 (EEG) and 274 (MEG) values for each of the 8 time intervals. These values were mapped on 2-D topographic maps (single sensors classification maps).

Results

Both EEG and MEG maps consistently showed an occipital activation (accuracy greater than 50%) corresponding to the first time interval (0-200 ms) which presumably contained the N100 component; a similar EEG-MEG consistency was found for an activation located over the central areas which corresponded to the third and forth intervals containing the P300 component, recognizable from the EEG.

Discussion and Conclusions

The consistency between the topography and components of the waveform expected to be generated by the performance of this task, and the accuracy of the classifier indicates that classification accuracy can function as an indirect measure of the brain processing workload. Although this approach still requires to be improved (for instance, by adopting different strategies to select the time intervals to be analyzed), we suggests that a BCI paradigm can be of value beyond classical application of a control channel.

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Support

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Keywords

BCI, P300, Classification Maps

L-23 Asynchronous control in a P300 task for domotic control

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Background and Objective

Present-day non-invasive Brain Computer Interfaces (BCI) determines the intent of the user from a variety of different electrophysiological signals [1]. The P300 potentials recorded from the scalp are one example of signals that can be used to determine the subject’s intent [2]. Indeed, P300-based BCIs have the advantage of requiring no initial user training, since the P300 is a typical, or naive, response to the presentation of a desired choice. Previous study indicated that a domotic environment can be operated by a P300-based BCI [3]. One of the main open issues relevant to this BCI application, concerns the low bit rate of command execution. Another interesting issue is the possibility for the user to disengage his attention from the interface without generates a wrong classification. In this study, we also addressed both issue by proposing asynchronous P300-Based BCI, we conducted experiments with four subject. The offline results show that the BCI is able to achieve an averaged information transfer rate of approximately 8 selection/min at a low false positive rate 5%.

Materials and method

Four volunteers were challenged in this experimentation. Scalp EEG data (8 channel EEG system; g.USBAmp, gTec, Austria ; sampling rate 256Hz) were acquired from each subject during BCI sessions operated by a BCI2000 software [4], with P3Speller application. Data were stored for offline analysis. The data acquired is composed by 6 run. In each trial we ask to the subject to pay attention during the odd trial at stimulation, counting mentally the number of occurrences relative at particular character (Control task) suggest by the system and to ignore the stimulation during the even trial (No-Control task). The data were processed in Matlab. The first step was extracting the control feature using the SWLDA, to discriminate two different classes, Target versus No-Target and No-Control. After we plotted a ROC curves for find the threshold to impose in the classification algorithms [5], the threshold is put out from an opportune choice between the True Positive Rate (TPR) and False Positive Rate (FPR), TPR > 0,5 and FPR < 0.05. The threshold value depend on the number of sequences accumulated. For improve the classification we impose another constrain, a hit is valid if the threshold is overtake two consecutive time, by the same stimulus.

Results

The rate of wrong classifications was below 4%. During control task, less than 15% of trials failed to reach the threshold for classification (missed classifications). During the no control task, about 2% of trials were incorrectly classified.

Discussion and Conclusions

These preliminary findings suggest that is possible to decrease the flash number for achieve the selection, and in the same time the threshold impose with this algorithms allow a the classifier to abstain when is a trial of no control. The next step will be implements this classification rule in a online signal processing, and testing it in a domotics contest. If the result in online utilization is confirmed we decrease the gap present in the BCI interface respect to the tradition input interface. And this will allow a direct comparison between it.

Keywords

Brain Computer Interface, Domotic appliance, Assistive Technology, Asynchronous control

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L-25 Inexpensive System for Experimenting with P300 and Other ERPs

Douglas Hains*, Chuck Anderson

Background and Objective

BCI systems based on event-related potentials require synchronization with stimulus events. Many EEG recording systems include ports for recording trigger inputs for synchronizing the recorded EEG with external events. Inexpensive systems, such as the MS-24R (for $5,600) from NeuroPulse-Systems, LLC, do not include trigger inputs. For such systems, we have designed a simple way to provide a trigger input on an EEG channel by means of a photo-diode placed over a corner of a computer monitor to detect flashes. We hope that this system, combined with our unique P300 detection algorithm, will result in an inexpensive P300-based speller.

Methods

This sensor is used in a P300-based speller application by highlighting a small rectangular area under the sensor in synchrony with each flash of a row or column of the usual P300-based speller display. A lowpass filter and threshold detection on the trigger signal is sufficient to identify the span of recorded EEG signals to be analyzed for presence or absence of the P300 wave. Real-time analysis of trigger and EEG signals is performed by custom, open-source, software, written in C++ and R [1]. We are developing a unique P300 detection algorithm based on our successful methods for mental task discrimination [2]. Data consisting of EEG recorded during attended and non-attended stimuli are time-embedded and used as training data for a quadratic discriminant analysis (QDA) classifier. The QDA classifier provides the likelihood of a P300 wave for each sample. These likelihoods are accumulated sequentially using a multi-hypothesis sequential probability ratio test (MSPRT) [3] following each flash. As soon as the confidence levels for a row and a column exceed a threshold, the corresponding letter is selected. In this way, the number of repetitions required for confident letter selection will depend on the data. Expected

Results

Experiments are underway with multiple subjects using our P300-based speller.

Results to-date show successful synchronization of row and column flashes with EEG. Our results were obtained by collecting spans of 700 milliseconds of EEG sampled at 512Hz from each intensification. The spans were collected so the 200 millisecond mark aligned with the trigger signal reaching a threshold of 2 microvolts. When averaging the spans corresponding to target intensifications, we have observed a P300 around 400 milliseconds after the trigger signal threshold was reached. We expect that the use of MSPRT to make decisions as soon as possible will result in a performance feedback situation that rewards the user's behaviors that result in faster detection.

Discussion and Conclusions

The combination of a very simple light sensor with an inexpensive EEG amplifier demonstrates how an affordable P300-based speller application can be constructed. The design is simplified by using an EEG amplifier designed only for EEG-level gains without the need for trigger ports. This simple approach can be extended to detect audible stimuli.

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Keywords

P300, synchronization, hardware, evidence accumulation

L-26 A framework for improved usability and scientific exploration of visual ERP-based spellers

Christian Puzicha*, Jeremy Hill

We present an update of the classic grid speller of Farwell, Donchin et al [1]. Our implementation, constructed in Python using the flexible BCPy2000 framework [2], is enhanced by several new features making it possible to address further scientific questions: - Arbitrary "codebooks" may be defined: these are matrices which dictate which letters flash when, and simultaneously with which other letters. If multiple codebooks are assigned, they are alternated trial-by-trial, for within-subject comparison of their relative merits (see [3]). - The ERP-inducing stimulus event may be a white-on-grey flash, or it may be easily changed to some other animation: this allows us to investigate the benefits of alternative stimuli which evoke different ERP components (for example, P300 and N200) to different extents [3, 4]. - Decoding is performed by a probabilistic classifier, and an inference over letters is made by applying Bayes' rule. This has three benefits: (a) inference over arbitrary codebooks rather than just row-column arrangements; (b) easy incorporation of a stopping criterion, by which stimulus presentation terminates when enough information has been gathered to reach a decision. (c) easy integration of predictive language models as priors, to enhance accuracy in natural language production. Our preliminary experiment measured 16-channel EEG from three subjects. We compared two codebooks within-subject: one (RC) flashes a whole row or column in each epoch; the other code (D8) was optimized to have larger Hamming distances between the flash sequences that encode the letters, (making each sequence as unique as possible) while at the same time avoiding flashes that occurred too soon after one another [3]. Our measure of efficiency is the number of flashes it takes the classifier to stop. The maximum number of epochs (rarely reached) was set to 72 per letter. All subjects performed well, making very few mistakes. The stopping threshold had to be adjusted to each subject to achieve satisfactory speed and accuracy (mean number of epochs: 28, 45, 21). The results were consistent across all subjects and thresholds: D8 needed significantly fewer flashes than the RC code to produce a correct letter (Mean +/- standard-error of the reduction in number of flashes, for each of the subjects: 6.7+/-0.6, 7+/-1.2, 6.8+/-0.68). Adjusting the probability threshold leads to a trade-off between accuracy and speed. No difference in accuracy is visible for the different codebooks, although by design the number of errors was too small to test this. Altogether we have shown that the optimization of the codebook and the probability threshold are usable means to dynamically adjust the trial length for improved handling of the speller. Our next step is the integration of a language model, to further reduce the spelling time for natural language while still allowing (slower) spelling of unnatural strings such as passwords. Future work may also investigate the user-training benefits of using a stopping criterion, since trial duration is a form of feedback about relatively good and bad attention performance, that is usable even when letter production accuracy is at ceiling.

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L-27 Online BCI based on attention to auditory streams: ERPs vs SSEPs

Jeremy Hill*

BACKGROUND AND OBJECTIVES

We aim to develop an EEG-based online BCI usable by completely paralysed users, for whom visual or motor-system-based BCIs may not be suitable. Our approach exploits covert shifts of attention to auditory stimuli. A similar paradigm was published as an offline study[1]: here we revive the method and produce a working online system, based on the BCI2000 software framework and implemented in

Python[2]. Whereas [1] exploited event-related potentials (ERPs), others[3] attempted to use auditory steady-state evoked potentials (SSEPs). They showed that SSEPs could discriminate which of two possible sounds was being played to the subject but (considering potential use as a voluntarily-operated BCI) could not discriminate which of the two was being *attended* when both were played simultaneously. Our question is: was this because their attention paradigm was somehow unsuitable for BCI, or more fundamentally because attention-modulation of SSEPs is too weak/noisy an effect?

METHOD

We presented concurrent (left and right) streams of periodic, ERP-eliciting "pulses", with periods 504msec (left) and 546msec (right). This difference made the streams uncorrelated over the 4.5-second duration of each binary trial. The difference between EEG responses following pulses on the attended and unattended sides was extracted and used to train a linear classifier. A pulse was a 100msec-long increase in the envelope of an ongoing sound: the ongoing sounds were AM waveforms with modulation frequencies 41.67Hz (left) and 38.46Hz (right). These evoked clear SSEPs at their respective modulation frequencies. Each subject performed 10 blocks, 20 trials per block. On each trial, subjects were instructed in advance which side to attend, and had to perform a discrimination task based on that stream while ignoring the other. After each block, a classifier was trained on all data so far. From the second block onwards, subjects received trial-by-trial feedback of the classifier's predictions.

RESULTS

Previously[4] we presented encouraging online results from 7 healthy subjects, measuring ERPs alone. Here we report results from 5 further subjects, for whom improved stimulus parameters allowed simultaneous evocation of ERPs and SSEPs. We found usable attention-modulation of ERPs in all subjects: online performance was above-chance on the first feedback block, and typically reached maximum by the third (average online accuracy per subject: 80%,75%,83%,94%,94%) SSEPs were assessed offline. EEG amplitude spectra showed sharp peaks at the AM frequencies during stimulus presentation, associated with fronto-central scalp distributions. Correlating the EEG with sine and cosine waveforms at the two exactly-known modulation frequencies, we obtained features that allowed discrimination of pre-stimulus from stimulus intervals at >90% accuracy for all subjects. However, these same features could NOT separate attend-left from attend-right stimulus segments.

DISCUSSION AND CONCLUSIONS

BCIs can be built based solely on EEG correlates of auditory attention to simultaneous stimuli. This is possible by measuring the attention-modulation of ERP components (latencies/scalp-maps suggest N2; to a lesser extent P3). Simultaneously, the attended stimuli can be designed to elicit clear auditory

SSEPs. These could discriminate stimulus from pre-stimulus EEG. However, attention-modulation of SSEPs was not sufficient for single-trial BCI communication, even when the subject's attention *was* clearly focussed well enough to allow classification of the same trials via ERPs.

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KEYWORDS

EEG, auditory, ERP, SSEP, ASSR, attention

L-28 Do People with ALS Perform Better with the Checkerboard Paradigm than the Standard Row/Column P300-BCI?

Sara Feldman*, Vincent Petaccio, Eric Sellers, George Townsend, Theresa Vaughan, Christopher Hause, Terry Heiman-Patterson, Jonathan Wolpaw

Background and Objectives

Brain-computer interfaces (BCIs) provide communication that does not depend on neuromuscular activity. Several studies have demonstrated that those with advanced ALS can use noninvasive BCIs (e.g.,1,2,3). In able-bodied users, Townsend et al2 showed that a pseudorandom -or checkerboard paradigm (CBP) significantly improves P300-BCI performance compared to the standard or row/column paradigm (RCP). The CBP flashes stimuli in quasi-random groups that do not contain adjacent items, and it ensures at least six flashes between flashes of a given item. The combination of these two factors improves accuracy and bitrate. Townsend et al [2] also reported anecdotal improvements with the CBP in people with ALS who had extensive experience with the RCP. The present study seeks to verify these results in a larger group of people with ALS.

Methods

The BCI users are people with ALS (ALSFRS-R scores between 0-33) The protocol is the same as that of Townsend et al [2] except that sessions may take place in the BCI user's home. Each flash lasts 187.5ms with 62.5ms between flashes. Each user completes one CBP session and one RCP session (with order counter-balanced across users). Each session begins with a no-feedback 38-trial calibration phase in which the user attends to specific items in an 8x9 matrix containing alphanumeric characters, function keys, and commands. After calibration, the user performs a 38-trial copy-spelling task using coefficients derived from a SWLDA [4]. For each user, the number of flashes used for the copy-spelling task is determined and converted to the written symbol rate (WSR)[5]. This measure reflects the maximum number of selections/min that the user can make assuming that s/he corrects every error (which in real life is often not necessary).

Results

In initial results from 4 people with ALS, accuracy is higher and fewer flashes are needed with the CBP than with the RCP. With the CBP, accuracy was as high as 100% with as few as three target flashes, corresponding to a WSR rate of 6.15 selections/min. The data from people with ALS appears to be more variable than that from able-bodied volunteers; however data from an age-matched control group is yet to be collected. The users with ALS report that the CBP is easier to use and produces less eye fatigue than the RCP.

Discussion and Conclusions

The initial data reported here suggest that the results obtained by Townsend et al[2] showing the superiority of the CBP can be replicated in an ALS population with little or no experience with a P300-BCI. With continued improvements, P300-based BCIs could restore significant capacity for independent communication and control to people severely disabled by ALS and other disorders.

Support

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Keywords

BCI; P300 event-related potential; amyotrophic lateral sclerosis; EEG

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L-29 Towards Clinically Acceptable BCI Spellers: Preliminary Results for Different Stimulus Selection Patterns and Pattern Recognition Techniques

Chandra Throckmorton*, David Ryan, Kenneth Colwell, Eric Sellers, Leslie Collins

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Background and Objectives

Individuals affected by severe physical limitations, such as those caused by amyotrophic lateral sclerosis (ALS) or brainstem stroke, may not have the physical ability required to use clinically available augmentative and assistive communication systems. The P300 speller relies on the detection of responses elicited in EEG signals and has been used as a method of technology access for individuals with significant disability 1, 2. Our research focuses on improving P300 spellers in two areas: improved pattern recognition techniques and channel selection techniques for detecting P300 event-related potentials (ERPs) in the measured multi-channel EEG data, and optimal stimulus selection for improved efficiency and performance.

Methods

In this poster we will present preliminary data in both pattern recognition techniques and stimulus selection performance. Participants will be recruited from the East Tennessee State University student subject pool. All subjects will perform three sessions: Row/Column 1, Checkerboard 2, and Random Illumination paradigm, all sessions will be counterbalanced and run on a on a 8x9 matrix of alphanumeric characters and commands. Each session will begin with a no-feedback calibration phase of 36 item selection to serve as training data for a SWLDA that will be used for online classification feedback during a subsequent copy-spelling task. Items will be flashed differently according to the type of paradigm: Row/Column will present full rows or columns (either 8 or 9 flashes in a group), Checkerboard will present quasi-random groups, and Random Illumination will present purely random groups of 6 items.

Results

Specifically, using previous BCI competition data, we present performance results for classifiers based on bagging techniques and Bayesian statistical analysis, standard classifiers such as LDA, and SWLDA. We also show new speller data and results where different flash patterns are considered and compare performance of traditional row-column flash pattern results .

Discussion and Conclusions

We expect to show that genetic algorithm optimization techniques will provide superior performance to standard classification techniques. We will also begin to examine optimal experiment design to guide stimulus selection groups. These paradigmatic changes should lead to improved P300-based BCI efficiency and performance (i.e. speed and accuracy).

Support

NIH/NIDCD (R21 DC010470-01)

Keywords

BCI; P300 event-related potential; amyotrophic lateral sclerosis; EEG

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L-3 Does the P300 Speller Depend on Eye-Gaze?

Peter Brunner*, Shubhada Joshi, Samuel Briskin, Jonathan Wolpaw, Horst Bischof, Gerwin Schalk

BACKGROUND AND OBJECTIVE

Many people affected by debilitating neurological or neuromuscular disorders such as amyotrophic lateral sclerosis (ALS), brainstem stroke, or spinal cord injury, are impaired in their ability to or even unable to communicate. A brain-computer interface (BCI) uses brain signals directly, rather than muscles, to re-establish communication with the outside world. One particular BCI approach is the so-called “P300 matrix speller?that was first described by Farwell and Donchin [1]. Ever since the original description of the P300 speller in 1988, it has been widely assumed that this method predominantly relies on the P300 evoked potential and not on visual evoked potentials (VEP). This assumption is of critical relevance to clinical application of this BCI method, because eye movements are often impaired or lost in the target population [2,3,4].

METHODS

This study investigated to what extent performance in the EEG-based P300 speller depends on eye gaze. We evaluated the performance of 17 subjects using the P300 spelling matrix implemented in BCI2000 [5] during two conditions. In one condition ("letter"), the subjects focused their eye gaze on the intended letter, while in the second condition ("center"), subjects focused eye gaze on a fixation cross that was located in the center of the screen, and simply attended to the intended letter.

RESULTS

The results unequivocally show that the performance of the P300 matrix speller substantially depends on eye gaze. This study thereby disproves the widespread assumption that the P300 speller does not depend on eye gaze.

DISCUSSION AND CONCLUSIONS

The results suggest that decreased performance in the "center" condition is due to the lack of negative early components 180 ms post stimulus over visual/occipital areas. Thus, these results provide strong evidence that the utility of the P300 matrix speller for subjects with impaired eye gaze may be limited.

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KEYWORDS

BCI, P300, matrix speller, eye gaze, EEG

L-4 Adaptive flashing: increasing the speed of the visual speller.

Peter Desain*, andrei Belitski, Jason Farquhar, Jeroen Geuze

Background and Objective

The classic Farwell and Donchin visual speller [1] works by sequentially flashing letters on a screen. Each flash of an attended letter evokes a p300-like EEG response. Because of its unique flash sequence the attended letter can be identified. In this way spelling a few characters per minute can be achieved. Next to modifying the layout and stimulus type, methods have been developed to improve the performance by optimising the flash sequences, exploiting the distance between codes and modeling refractory periods. To further improve its rate, the speller can be made adaptive by stopping when a confidence limit is reached. One may even abandon fixed, pre-constructed sequences and decide online which set of letters to flash such that the expected error probability is minimized, given the current estimated target letter probabilities. Finding such a minimum error letter-set is combinatorially intractable in the general case. However, in certain cases an exhaustive search is possible or even easy, e.g. for row-column coding. A complicating factor is the latency of the response, i.e. a flash needs to be decided on before the classification response to the previous flashes is completely available.

Methods

There are similar problems for which tractable algorithms are known. For example, Huffman coding optimally solves the problem of building a tree of binary decisions to identify a chosen symbol given prior probabilities over the symbols. Alternatively, one can maximise the information gain (or entropy reduction) from a flash as an approximation to the error probability. Based on the formalization in [2], and modeling the latency of responses, we ran monte-carlo simulations of different adaptive policies: expected-error, entropy-reduction, (both exhasustive and greedy), Huffman and row-column flashes. For low numbers of letters and single selections we were able to compare the different policies exhaustively for all initial letter probability distributions. For 3 symbols the resulting trajectories and the effects of adaptive rules can be visualized, aiding the understanding. In these results the initial state was given by a language model: letter and digram frequencies. In this case the row-column policy was further optimized by arranging the letters in the matrix such that rows and columns are balanced in probability.

Results

The simulations show that the Huffman scheme performs well, but still below what is possible with greedy search which in turn was slightly worse than exhaustive search. Further, the entropy-reduction was slightly worse than expected error minimization. Optimizing the layout for row-column flash sequences had a minor effect. These simulation results seem to be confirmed by our preliminary physical experiments.

Discussion and Conclusions

Adaptivity is the next step in improving BCI's. In stimulus driven BCI's, like the visual speller, a simple online choice of the next stimulus to present as a probe is an elegant and effective method for that. Simulation and initial experiments show that in this way significant improvements in performance can be achieved.

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Support

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Keywords

(maximum of 6) P300 Speller, Value of Information Theory, Huffman coding, Adaptive BCI

L-5 Strategies for decoding in the visual speller system

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Introduction

State of the art decoding methods for visual speller data are discriminative and involve the classification of epochs of EEG data with binary labels. These methods in general do not asses which character which has the largest probability of being the communicated character given the brain data (MAP solution) but optimize the classification performance of the epochs. We propose a graphical model framework for a MAP decoding of visual speller data.

Methods

We start from a graph showing the dependencies between the variables, in our case the EEG epochs and the epoch labels. Letter priors can be incorporated in the graph. From this graph a maximum a posteriori decoding rule can be derived. The decoding involves learning some conditional dependencies from the brain data. We perform the learning using a generative and a discriminative approach. We tested the learning methods on 16 visual speller datasets, 6 of which had a flat letter prior and 10 of which had an english letter prior.

Results

First, the generative approach yields good letter prediction accuracy at a faster learning rate than state-of-the-art decoding methods . This implies that the period during which training data is gathered can be shortened, a desirable property in BCI research. Second, the incorporation of letter frequency information improves the letter prediction performance.

Discussion and Conclusions

The study gives insight into different strategies for the decoding of visual speller data.

Keywords

visual speller, decoding, graphical models, generative methods , discriminative methods , letter frequency information

L-6 Motor Disability, Speech Disability, and Task Performance in a P300-based Brain-Computer Interface

Chang Nam*, yueqing Li

Background and Objective

The main goal of this study is to investigate relationship between the disability level (motor ability and speech ability) and user performance in two different interfaces through a series of regression analyses. User performance between participants with ALS and those with CP was also assessed.

Methods

Participants: Ten participants with motor disabilities (3 ALS or 7 CP) were employed in the study. Data Acquisition and Processing: P300 brain waves were recorded using an EEG cap (Electro-Cap International, Inc.) embedded with 16 electrodes covering F3, Fz, F4, T7, C3, Cz, C4, T8, CP3, CP4, P3, Pz, P4, PO7, PO8, and Oz, based on the modified 10-20 system of the International Federation (Sharbrough et al., 1991). Recordings were referenced to the right mastoid and grounded to the left mastoid. Electrode impedances were all less than 5 kO. P300 brain waves were amplified with a g.USBamp amplifier (g.tec Medical Engineering). The EEG was filtered by a 0.5 Hz high pass filter and 30 Hz low pass filter, also notch filtered between 58 Hz and 62 Hz. P300 brain waves were digitized at a rate of 256 Hz. Data collection, control, and off-line signal processing were all conducted by the BCI2000 system. Independent variables: Participants?motor abilities and speech abilities were rated by ALS Functional Rating Scale from the ALS CARE PROGRAM. Higher score represents better motor ability or speech ability. A traditional P300 speller interface (ABC interface) and a frequency-based interface (EIU interface) newly designed according to the use frequency of the English letters were used in the study. Dependent variables: Accuracy rate, information transformation rate (ITR), amplitude and latency were used as dependent variables.

Results

Motor ability and user performance ABC Interface: No significant linear relationship was found between participants?motor ability and user performance. EIU Interface: A significant linear relationship was found between participants?motor ability and amplitude, $F(1, 8) = 14.92$, $p < 0.05$. As the participants?motor ability increases, their amplitude decreases with the slope of 0.52. No significant linear relationship was found between participants?motor ability and user performance such as accuracy, ITR and latency. Speech ability and user performance ABC interface: No significant linear relationship was found between participants?motor ability and user performance. EIU interface: No significant linear relationship was found between participants?motor ability and user performance. But, the results showed a strong relation between participants?speech ability and accuracy, and between speech ability and latency. As the participants?speech ability increases, accuracy increases while latency decreases. Performance of Participant with ALS or CP The results showed that participants with ALS had better performance than those with CP, especially in accuracy and ITR.

Discussion and Conclusions

As opposed to common knowledge, there was no significant linear relationship between disability level and task performance, although a stronger relationship was found for EIU interface than ABC interface. We also found difference in user performance between participants with ALS and CP. More studies are required to support this finding due to the small sample size used in the present study, but we will provide a full discussion on these results in the full paper. The results of the present study should give some insights into the future research of the P300-based BCI systems, as well as the real-world applicability of the P300-based BCI applications as a non-muscular communication and control system for people with severe motor disabilities.

Keywords

P300-based BCI, user interface, motor ability, speech disability

L-7 Classification accuracy of the P300 based BCI depends on the location of the target character in the matrix.

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The P300 Brain Computer Interface (BCI) presents a user with a matrix of options for communication. The user focuses attention on the desired character, the rows and columns of the matrix are randomly highlighted and by detecting which row and column flash elicit a P300, the BCI identifies the target character. Some users reported that they found it easier to attend to characters in particular areas of the matrix. We investigated, therefore, the degree to which the accuracy of the P300BCI varied across the different cells of the matrix. Each of the 6 subjects focused attention in turn on each of the matrix cells. A spatio-temporal principal component analysis (PCA) on the data from16 electrodes revealed two major components. One component was clearly identified as the P300. The second component appeared as an earlier frontal positivity possibly representing a P3a, or a novelty P3. It turns out that this second component also strongly differentiated between the response to target and non-target flashes. The factor scores of both factors were statistically analyzed with respect to target position in the matrix. For the column flashes the P300 was smallest when the target character was located in the top rows compared to the bottom rows. On the other hand, for the row flashes the frontal factor was smallest when the target was located in the bottom rows. An analogous statistical analysis was conducted on the classification accuracies estimated by a bootstrapping approach when one, three and six flashes were included in stepwise-linear discriminant analysis based BCI classification. Accuracy was poor when the target was in the lower rows. This effect disappeared when six flashes were used. Thus, it appears that target position does play a role in the BCI accuracy when a small number of flashes is used. However, this cell effect is not observed when at least 6 flashes are used in the average. The presence of both a P300 and a large P3a component in our data was unexpected. Therefore, in an additional analysis using the factor scores obtained in the PCA and stepwise linear discriminant analysis, we compared the utility of using information just one of the components, or both together in the classification process. The results will be discussed and our conclusions will lead to important implications with respect to optimizing classification rules in the future.

L-8 Suppressing Surrounding Characters during Calibration may Improve P300-based BCI Performance

Gerald Frye*, Christopher Hauser, George Townsend, Eric Sellers

Background and Objectives

Since the introduction of the P300 BCI speller by Farwell and Donchin1 speed and accuracy of the system has been significantly improved. Larger electrode montages and various signal processing techniques are responsible for most of the improvement in performance. The present study takes advantage of a new presentation paradigm to improve performance, the “checkerboard?(CB) paradigm2. The CB presents quasi-random groups of six items instead of using the typical row/column presentation. To determine if reducing distraction from neighbouring items could improve subsequent performance on a copy-spelling task, the CB paradigm was used and compared to a condition that suppressed (i.e., did not flash) items during the calibration phase of the experiment.

Methods

Six subjects have participated in the study. Using an 8x9 matrix of 72 items, the participants?task is to copy-spell 36 items. Each participant has completed one session using the CB during calibration and another using suppression (SR) during calibration. Each session begins with a calibration phase consisting of 36 items, in which no accuracy feedback is presented, and each target item flashes 10 times out of 120 total flashes. The duration of each flash is 62.5ms with 62.5ms between flashes. Subjects attend to a specific item and count the number of times it flashes to hold attention on the task. The calibration data is submitted to a SWLDA3 procedure to derive a classifier that is used for online feedback during the copy-spelling task. The Written Symbol Rate (WSR)4 is used to optimize the number of flashes for copy-spelling. The WSR calculates the number of flashes necessary to obtain the highest number of selections/min for each subject, and each condition. The copy-spelling task was identical to the calibration phase with the exception that accuracy feedback was presented after each item selection, and the number of flashes was reduced when applicable.

Results

Online accuracy is significantly higher in the CB condition, 94% as compared to 86% correct in the SR condition. However, mean theoretical bit rate (bit rate not including time between selections) is equal in the two conditions (CB=44 bits/min; SR=48 bits/min) due to subjects using fewer flashes in SR (4.6 vs 6, on average). Although waveform morphology is similar, the latency of the late negative peak at electrode location Pz is at 400ms in SR and at 460ms in CB. We will collect data with another twenty subjects.

Discussion and Conclusions

These preliminary data suggest that suppressing the items surrounding the target can enhance performance by deriving a more robust classifier when it is cross-validated on calibration data. However, when the classifier is generalized to non-suppressed data, accuracy decreases but remains relatively high. In fact, bit rate between the two conditions is not different.

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Keywords

BCI; P300 event-related potential; amyotrophic lateral sclerosis; EEG

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L-9 Effects of cardiac autonomic balance on performance in a P300 brain-computer interface

Tobias Kaufmann*, Claus Vögele, Stefan Sütterlin, Steve Lukito, Andrea Kübler

BACKGROUND AND OBJECTIVE

Brain computer interfaces (BCI) can serve as communication tools for people with severe impairment in speech and motor function due to neurodegenerative disease. Reasons for large inter-individual differences in people's ability to use a BCI are not yet understood and predictors for BCI performance would be advantageous for the selection of users and EEG parameters. For BCI-based communication by spelling, paradigms making use of the P300 evoked potential are widely used. Success in a P300 based BCI requires the ability to cognitively modify the focus of attention and to sustain attention. Such attentional control has been closely linked to peripheral physiological parameters, such as the heart rate variability (HRV). The present study investigated the association between resting HRV and performance in the P300 BCI.

METHODS

Electrocardiogram (ECG) of 29 healthy participants was recorded and a P300 based BCI spelling task performed. HRV resting baseline was determined for five minutes before and after BCI performance. The BCI task consisted of a calibration session and afterwards a monitored trial during which participants were required to spell 12 words of five letters each (12 blocks). The blocks were interspersed with 30 second breaks (recovery times). Time and frequency domain of the resting HRV was analysed.

RESULTS

Autonomic balance (LF/HF) and other HRV measures were associated with BCI-performance such that subjects with higher HRV performed better ($r=-.53$, $n=18$, $p<.05$). Autonomic balance explained 23,1% of the variance in BCI-performance.

DISCUSSION AND CONCLUSIONS

How can we identify whether people could use a BCI, and which BCI might be best for each user? This abstract shows that HRV, which is easy to measure, might predict successful performance with (at least) the P300 BCI system used here, across an admirable number of subjects. These results contribute to a better understanding of interindividual differences in BCI performance in healthy individuals and potentially also in clinical samples.

KEYWORDS

P300 BCI, Heart rate variability (HRV), BCI performance

L24 The P300-Based Visual Speller for People with ALS: Insights from Initial Evaluations

Lynn McCane*, Joseph Mak, Theresa Vaughan, Dennis McFarland, Laurra Tenteromano, Debra Zeitlin, Phillippa Tsui, Eric Sellers, George Townsend, Steve Carmack, Jonathan Wolpaw

Background and Objective

Most healthy young people can use a visual P300-based speller in a controlled laboratory setting1. Previous studies in people with severe disabilities have been limited to relatively small populations [2,3,4] or have been in populations with a variety of different disorders [5,6]. Here, we evaluate the performance of a larger population of people severely disabled by ALS. We sought to identify factors that affect performance and methods for improving performance. The study is part of a program that is providing the P300 speller for long-term independent home use.

Methods

The subjects were 20 people with ALS (15 men and 5 women, ages 41-67 yrs, ALS Functional Rating Scale 0-13, 17 using mechanical ventilation). In general, they had little remaining useful motor control, had decided to accept mechanical ventilation if needed, were in otherwise stable health, had supportive living and social environments, and were concerned about the long-term adequacy of their current communication device. We recorded 16 channels of EEG from frontal, central, and posterior scalp locations (F3, Fz, F4, T7, C3, Cz, C4, T8, CP3, CP4, P3, Pz, P4, PO7, PO8, Oz) using a16 Channel Electro-Cap and the BCI2000 software platform7 while the person viewed the standard 6x6 P300 matrix of letters and numbers 8 and groups of items flashed rapidly. The person was asked to attend to a succession of specific items. Data collection continued over about 50 min. with short breaks interspersed. Data from 8 channels (Fz, Cz, P3, Pz, P4, Po7, Po8, Oz) for the first 21 selections were then processed and classification coefficients were derived by a stepwise linear discriminate analysis9. These coefficients were then applied to 14 subsequent selections and the online BCI accuracy for these selections was determined.

Results

The subjects fell into two distinct groups in regard to accuracy. For 13 people, accuracy was >70% (71-100%). For the other seven, accuracy was <30% (0-29%). (Chance accuracy was 3 %.) ALSFRS score and performance were not correlated (p<0.05). Six of the seven with accuracy <30% had visual problems such as severe ptosis or nystagmus. In the group with accuracy >70%, maximum P300 amplitude was more anterior than in the <30% group (11 of 13 had frontal or central peaks). The parietal and occipital channels dominated the SWLDA coefficients. Offline comparison of the 8- and 16-channel montages gave comparable results for performance. Offline evaluation of fewer selections to develop weights resulted in an increased number of users performing below 70%.

Discussion and Conclusions

The results imply that: (1) the standard 8-channel P300 montage appears to be adequate for this user group; (2) about two-thirds of those severely disabled by ALS can use the visual P300 speller; (3) visual problems are the dominant reason for inability to use the speller; and (4) development and deployment of an auditory P300 speller could serve people with ALS when visual limitations prevent their using the visual version.

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Key Words

P300 BCI, ALS, Event Related Potential, Augmentative Communication

M-1 Goal Selection versus Process Control while Learning to use a Brain-Computer Interface

Audrey Royer*, Minn Rose, Bin He

Multiple control strategies exist for use in brain-computer interfaces (BCIs). Two strategies, process control and goal selection, differ in how they use the signal from the brain. In process control, the brain's signal is used to control all the fine details of the BCIs motion: position, velocity, acceleration, etc. In goal selection, the brain's signal is used to determine the user's overall intent, or goal. Once the BCI determines the user's goal, the fine details of motion are controlled by the BCI. Normal motor control involves the cooperation of many parts of the central nervous system including the cortex, basal ganglia, cerebellum, and spinal motor neurons. Since BCIs typically only obtain their signal from the cortex, goal selection may be a more natural control strategy which would be faster, more accurate, and easier to learn. The objective of this study is to determine the effects of control strategy, i.e. goal selection or process control, on a subject's ability to learn to effectively use a BCI. We directly compared goal selection and process control in BCIs that differed only in the overall control strategy. Each BCI used scalp-recorded EEG to record sensorimotor rhythms from motor imagination and moved a computer cursor in one-dimension according to the same underlying signal processing. Twenty young healthy human subjects were randomly assigned to one of four paradigms. Two of the paradigms were based on goal selection and two were based on process control. While wearing a 64 electrode EEG cap, subjects operated the BCI for eight sessions. Sessions lasted approximately two hours and occurred roughly once a week. Sessions consisted of 5 screening runs without feedback, followed by 10 feedback runs, and

concluded with 5 more screening runs without feedback. The screening runs were used to individualize the electrodes and frequencies used as the control signal for each subject. Since subjects were instructed to use motor imagery, chosen frequencies were limited to the alpha and beta bands, and electrodes were limited to ones over sensorimotor cortex. At the end of the 8 sessions, the best subject from each group performed 2 sessions of all 4 paradigms in a random order. This study shed light on how the EEG signal changed as subjects learned to use a BCI. Additionally, our results showed that goal selection surpassed process control in every measure studied. Goal selection had a higher information transfer rate, more hits in an average run, was faster in use, more accurate, and required less effort than process control. Those same measures improved faster and more consistently for goal selection than for process control. This shows the importance of control strategy to a subject's ability to learn to effectively use a BCI.

Support

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Keywords

(maximum of 6) BCI, motor imagery, sensorimotor rhythm, control strategy, EEG

M-10 Operant conditioning vs. application of strategies in a neurofeedback based SMR BCI.

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Background and Objective

Many Brain-Computer Interfaces (BCI) rely on the regulation of sensorimotor rhythms (SMR) of the EEG by means of neurofeedback. According to Lacroix's Two-Process Theory of neurofeedback learning, subjects either identify efferent programmes already in their behavioural repertoire which allow them to achieve control over the targeted physiological signal. If so, subjects use the provided feedback to refine these strategies. If no strategy is available afferent processes underlie the acquisition of autonomous control to construct a new behavioural programme (1). The second process equals the operant conditioning approach in which physiological responses are altered and if this manipulation leads to the desired result these responses are positively reinforced and subsequently more often applied. In the current study, we aimed at investigating how learning to control an SMR-based BCI differs as a function of the process ?efferent vs. afferent - by which such control is instantiated. We hypothesized (1) that subjects who are instructed to imagine a movement present with a higher initial performance and that for this reason (2) the course of learning would be less pronounced. Further, we predicted that (3) the end performance would not differ between the groups.

Methods

Nineteen healthy BCI novices were randomly assigned to an “efferent?group (EG) and an “afferent?group (AG). EG subjects were instructed to kinesthetically imagine the movement of their right hand. The AG was instructed to focus their attention on the feedback signal and observe how its trajectory changes in relation to different thoughts. In both groups subjects were required to move a cursor into one of two targets. A decrease of the power in the alpha band over EEG channel C3 moved the cursor to the bottom target, and an increase of the power to the top target. The EEG was recorded with a 16 channel EEG amplifier. Correct response rate (CRR) in % served as measure of performance.

Results

Initial and final performances were 61.9/67.36% in the EG and 50.9/62.8% in the AG. Performance was significantly better in the last session when compared with the first session ($F(1,17) = 8.7$, $p < .01$), but the group differences and interaction were not significant (2 (session) x 2 (group) repeated measures ANOVA). Both groups learned significantly during the course of 10 sessions (linear trend EG: $F(1,8) = 9.7$, $p < .05$; AG: $F(1,8) = 139.5$; $p < .001$; power trends also significant). Learning was more pronounced in the afferent group ($F(1,17) = 397.3$, $p < .001$).

Discussion and conclusion

As expected, both groups learned and the increase in learning rate was greater in the afferent group. Although, on a descriptive level, the efferent group performed better in the first session compared to the afferent group, this difference failed to reach significance. End performances were not significantly different between the groups. The high variance in performance and the low overall performance which is atypical for SMR-BCIs may have been due to not determining the best motor imagery and the best electrode for each subject. However, a screening session to identify which motor imagery works best for each subject at which electrode could not be performed in this study, as it would have revealed the motor imagery strategy to all subjects. We conclude that motor imagery is not necessary to regulate the

SMR amplitude and cautiously, that providing a strategy only improves the initial performance, which might be important to sustain motivation for BCI training.

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Support

This work is supported by the European ICT Programme Project FP7-224631. This paper only re?ects the authors?views and funding agencies are not liable for any use that may be made of the information contained herein. keywords: Brain-Computer Interface, EEG, BCI subject training, neurofeedback learning strategy, sensorimotor rhythms (SMR), operant conditioning

M-11 Merging EEG and eye behavior data to improve BCI target detection

Stanley Klein*

Stanley Klein (1), Thom Carney (1), Claudio Privitera (1), Sangita Dandekar (1), David Kim (1), Mario Aguilar(2), Ming Qian (2), Patrick Connolly (2), (1)University of California, Berkeley; (2)Teledyne Scientific Company Background and Objective.

For the past five years we have been working on a DARPA supported project titled Neuroscience for Information Analysts (NIA). The goal of this project has been to combine advanced EEG methods , eye tracking and machine learning to speed up image analysts' ability to detect unusual occurrences in the imagery being viewed. A major effort was placed on fusion of data from multiple sources: event related potentials, frequency domain power and coherence, eye movements and pupil size. The recent publications of Yuval-Greenberg, et al. (2008) and Dimigen, et al. (2009 and supplement) show that task dependent microsaccades produce EEG signals that are commonly misinterpreted as high frequency oscillations, making high quality eye tracking all the more important for BCI applications. Our research explores how the multiple sources of information complement each other.

Methods

EEG data is acquired with a Biosemi system using 64 channel caps. The EyeLink 1000 is used for eye tracking at 1000 Hz and 0.25 deg resolution. Hidden Markov Modeling of the eye movement information is used to reveal the constantly shifting attentional state and decision stage of the observer. A linear regression methodology using eye velocity spikes as regressors has been developed to isolate the saccades from each other. The observer's task is visual search using a variety of target visibility, prevalence and clutter. A multi-stage machine learning algorithm using linear discriminant analysis was used to combine information from multiple sources in order to separate targets from distracters. As a measure of success we used both the signal detection theory area under the ROC curve, and also a fixed criterion d' measure at a 5% false alarm rate.

Results

In extensive studies with central fixation we found that inclusion of the EEG information produces a >5-fold increase in targets detected per unit time, while keeping a very low false alarm rate. This speedup was achieved by using a two-stage method in which an EEG based "triage" paradigm detected most targets and a second stage was used to eliminate false alarms. Fusion with pupil information significantly increased detection efficiency. In our free viewing conditions we have found that scanpath eye movements and their associated EEG responses have been successful in classifying properties of the objects searched for.

Discussion and Conclusions

One of the advantages of our EEG/scanpath method is that it produces far more hits per unit time than any approach without using EEG. In a sense our approach is a triage approach of eliminating most of the distracters. By removing the eye movement artifacts and by classifying the fixational scanpaths using Hidden Markov modeling we have significantly improved target detection. We conclude that non-invasive BCI should include a high quality eye tracker so that as many as possible fixational microsaccades are detected. The standard EOG information doesn't have the sensitivity to detect a sufficient number of microsaccades. Fusion of eye movement information and EEG has the potential for important progress in non-invasive BCI technology.

M-12 Exploring the Effects of Individual Characteristics on Mental Training and Control

Adriane Randolph*, Ashley Ingraham

Keywords: individual characteristics, training, control, brain-computer interface

Background

Objectives of the Kennesaw State University BrainLab The Kennesaw State University (KSU) BrainLab is expanding upon the mission of the original BrainLab by exploring applications that may be used in mainstream, organizational settings, as well as for individuals who may experience being “locked-in?to their bodies. In particular, we are working to understand the impact of individual characteristics on the control of brain-computer interface (BCI) systems. This work seeks to serve as a foundation for evaluating and significantly improving the design and use of BCI systems. Individual Characteristics Everyone does not experience equal success with controlling a BCI; where someone is able to control a particular BCI technology with great reliability, another cannot control it at all. The match between an individual and technology is an individual-technology fit and can be reflected by the individual’s performance with the technology. A methodology that explains performance with available brain-computer interface technologies based on individual characteristics can greatly expedite the technology-fit process, where characteristics are a person’s demographic, physiological, and cognitive traits. Mental Training and Control An exploratory study showed that three characteristics were seen to significantly relate to control of a functional near-infrared (fNIR) BCI device: age, regular caffeine consumption, and years of education [1, 2]. Additional work has been launched in the KSU BrainLab to explore the effects of individual characteristics on a mu-based BCI and how mental training relates to motor skills. Previous studies showed that motor skills related to mu-based control [3], but did not consider a wider range of characteristics and their effects.

Methods

As part of a pilot study, three non-disabled participants (2 male, 1 female) were screened and underwent five days of mu training. Each session consisted of five runs of 3 minutes each according to protocol recommended for the BCI2000 software [4]. On the first and last days, participants were asked to play a best-of-three tennis match on the Nintendo Wii console (http://www.nintendo.com). This established their baseline abilities on the Wii without and with mu training. Participants were fitted with an 8-channel electrode cap running with the BioSemi bioamplifier (www.cortechsolutions.com).

Results

Overall, the results were inconclusive; only one of the three participants showed improvement in his/her motor skills as measured by the Wii and shown in Table 1. Table 1. Wii skill scores in tennis for participants undergoing mu training. Participant Session One Session Five 01 98 60 02 70 64 03 103 118

Discussion and Conclusions

There were a number of factors that may have affected the results including mental fatigue, affective medication, and previous training experience. However, more work is underway to confirm the links between initial controllability, training, and motor skill enhancement where differences in individual characteristics may ultimately be the deciding factor.

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M-13 Cue variation in a motor-imagery task

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CUE VARIATION IN A MOTOR-IMAGERY TASK Andrew Geronimo(1), Mst Kamrunnahar(1), Steven J. Schiff(1,2) 1 Center for Neural Engineering, Dept. of Engineering Science and Mechanics 2 Depts. Of Neurosurgery and Physics Penn State University, USA

Keywords

motor-imagery, biofeedback

Background and Objective:

Electroencephalogram (EEG)-based motor-imagery paradigms rely on the use of cues for subject instruction. Often, these cues are presented imbalanced in the subject's visual field. The neurophysiologic consequences of these cues are often overlooked and can lead to asymmetric evoked potentials which may contaminate the EEG as artifact. In motor-imagery tasks, where hemispheric differences are used to determine subject intention, the introduction of imbalanced evoked responses would falsely suppress or exacerbate these differences, thereby affecting classification accuracy due to motor-imagery. The objective of our study was to observe the effect of cue presentation on classification accuracy during a closed-loop BCI experiment.

Methods

After open-loop experimentation with four subjects, three subjects have participated in a closed-loop motor-imagery experiment. Depending on the cue presentation, the subjects were asked to imagine either movement of the left arm, right arm, or no movement. Three sets of cues were used: A long balanced arrow, a short balanced arrow, and an unbalanced arrow as a control. EEG data were collected from a bipolar arrangement at the C3 and C4 sites in the standard 10-20 configuration. For feedback, these channels were each processed into two filter banks of alpha (8-12Hz) and beta (16-24Hz) bandpowers. These bandpower channels were combined with weighting functions from a training run to become the feedback variable. The visual feedback was comprised of a horizontal bar that became green when the algorithm determined the subject was imagining the correct direction of movement. The feedback became red if the opposite occurred. The objective of using this feedback was to limit excess eye movement from a feedback presentation that utilized an object moving across the visual field.

Results

To analyze any trends in feedback accuracy in the closed-loop paradigm, each trial was split into four periods: an early stage including the 500 ms following cue presentation, a middle stage (the following 2500 ms), a late stage (the following 2250 ms), and a post-feedback stage, which includes the last second of each trial. Preliminary findings are that for each arrow cue, the classification accuracies were generally greatest in the late stage for all subjects. Each cue was also assessed individually to make a comparison in the classification accuracies of symmetric vs. asymmetric arrows. The short, balanced arrows yielded the best results , whereas the long, balanced arrows performed worst.

Discussion and Conclusions

Ongoing research includes acquiring additional data from more subjects to generalize classification accuracy from our paradigm. The recordings will be further examined as a composite of visually evoked potentials as well as continued attention related potentials and imagery-induced modulation. Along with typical bandpower features of imagery modulation, features of these evoked potentials and continued attention related potentials will allow for superior task discrimination.

M-14 Passive BCIs for detection of Covert Aspects of User State and enhancing Human-Machine Systems

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BACKGROUND AND OBJECTIVE

Interaction between machines and human beings in general is dominated by explicit manual actions, demanding a high degree of awareness from the user. A large portion of information on the actual user state ?like mood, internal interpretations or other cognitive processes ?can, if at all, only with difficulty be inferred from such interactions. These covert aspects of user state (CAUS) are highly relevant for an adaptation of the machine to its user. As most of them are still not accessible by technical systems the interaction with machines is still rather unnatural when compared to social interaction. Brain-Computer Interfaces (BCIs) have proven being able to provide information on actual cognitive processes of humans. Until now, this has mainly been used for providing a direct input channel for communication and control. We, Team PhyPA, propose to utilize this technology for accessing CAUS and generating an elaborate adaptation of the machine to its user. In the last four years we have proven that the resulting technology of passive BCIs (Zander et al., 2009) indeed is capable to access several CAUS and to use this information for enhancing Human-Machine Interaction (HMI).

METHODS

We have conducted several experiments for accessing CAUS. Here we present one related to the human error processing, leading to better adaptation and hence higher efficiency in HMI. For simulating a typical HMI we have designed a game. The goal is to rotate a stimulus, until reaching a given target. The stimulus automatically changes colors in 1000 ms intervals. Color indicates the angle of rotation upon key press. Only one press is possible per color phase. Players are free to choose pressing a key. In a second stage of the game we have introduced erroneous behaviour ?on a chance of 30% a change in color mapping occurred, which was unexpected and slowed the player down. Our hypothesis was that (visual) perception of this misbehaviour would evoke an ERP which is detectable in single trial. The resulting passive BCI would then provide information which can be used to correct the previous misbehaviour of the machine automatically and hence enhance the performance of the player. We have invited 13 naive subjects for playing the game and recorded 56 channels of EEG. From that we extracted features with a derivative of the pattern matching method (Blankertz et al, 2003). Upon the data of an initial trainings session we have built a regularized linear discriminant function which has then been applied in a validation session.

RESULTS

The mean classification error for the automated error detection was 15.3 % with a standard deviation of 5.0 %. The false positive and negative rates were balanced. With this, the loss of performance induced through the misbehaviour of the machine could be counterbalanced by 64% on average.

DISCUSSION AND CONCLUSION

This study shows that it is possible to enhance the efficiency of HMI via passive BCI. By providing the machine with information about the perceived errors, it was able to adapt its actions to the associated CAUS. Hence, the spectrum of BCI technology is broader than initially expected. It also could lead to new and valuable applications even for healthy users.

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M-15 A Portable and User-friendly SSVEP-based BCI System

An Luo*, Thomas Sullivan

Background and Objective

We present a user-friendly BCI system based on steady-state visual evoked potential (SSVEP) that is also low-cost, low-power and portable. The system is battery-powered and is comprised of two components: an EEG device with a single dry sensor; and a stimulus box controlled by an internal microcontroller. A dry sensor proves to be more convenient, comfortable and cost effective than traditional gel-based multisensory EEG systems; and the microcontroller-based computation is much more portable, cost-effective, and energy-efficient compared to computer-based BCI systems. The visual stimuli have been carefully designed such that potential risk to the photosensitive patients is minimal. A novel classification algorithm is embedded in the microcontroller which does not require an accurate clock source. This system does not use a computer, is safe for most people and is easy to setup. It can be widely used for both commercial and research applications.

Methods

Our single dry-sensor EEG device does not require any conductive gel and can be easily put on or taken off from a user. To record EEG, the user simply puts the EEG cap on and adjusts the sensor so it is on the right scalp location, and a recording can begin. The microcontroller inside the stimulus box controls four LED panels on the box surface to flash at different frequencies, receives EEG data through a serial wire, performs real-time classification, and presents the decision. The microcontroller also sends out the decision to a serial port of the stimulus box, which can be used to control some external devices. This stimulus box is powered by four AA batteries and can last for days without charging. The visual stimuli have been carefully designed such that potential risk to cause seizure to photosensitive patients is minimal. When viewed from a distance of one foot or above, our flashing stimulus is safe according to generally accepted guidelines [1, 2] for lowering the risk of triggering photosensitive epilepsy (PSE) seizures. We use a novel time-domain method which computes the average event-related potentials time-locked to the visual stimulus. Linear discrimination analysis (LDA) is used to classify the EEG data in real-time. This algorithm does not require prior knowledge about the frequency of the flashing stimulus or the response waveform of a user. The only information it requires is the relative timing of EEG and the flash onsets, which are generated by the microcontroller inside the stimulus box.

Results

The performance of a previous version of the system has been extensively studied and reported [3, 4]. That system works for 12 out of 14 subjects, with an average correct detection rate of 75.8% and a false positive rate of 8.4%. The information transfer rate (ITR) is 34.3 bit/min for one subject.

Discussion and Conclusions

We introduce a portable SSVEP-based BCI system using a single dry-sensor EEG device that is also low-cost, energy-efficient, and safe. A more extensive study has been planned to fully test population performance of this system.

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Keywords

EEG, Brain-computer interface (BCI), Steady-state visual-evoked potential (SSVEP), dry-sensor, microcontroller, time-domain algorithm

M-16 Subject decoupled maximal SSVEP bit rate

Eric Liauw*, Bruce Gluckman

Background

Steady state visual evoked potentials have already been applied for BCI control. SSVEP allow for multi class control of a system. The number of choices a user can choose from at a single instance is only limited by the number of frequencies which can be detected in the in the EEG. It has been shown that SSVEP can be used for selecting 1 of 12 choices on a telephone keypad. Bit rates of up to 70bits/min using SSVEP have been reported [1]. In all current work, reported bitrates depend on system performance and human performance. Human performance is difficult to evaluate and we have designed a model which minimizes the effects of human performance in order to determine the maximum bit rate achievable from SSVEP.

Methods

The SSVEP signal is a periodic evoked signal in the EEG. We use multi-taper spectral analysis to analyze the periodic signal. Multi-taper spectral analysis allows us to average over orthogonal windowing functions (Slepian tapers) for each time period, minimizing the variance in the estimate. [2] The analysis of SSVEP only requires spectral estimates for frequencies of interest. In the case of SSVEP's, estimates only have to be made for bands around the stimulus frequencies. By limiting analysis to frequencies near the stimulus frequencies and doing computation in time domain, we can reduce the computational cost. To minimize the effect of human performance, we use a single LED for the SSVEP stimulus. The LED is flashed at 4 set frequencies (36Hz, 41Hz, 46Hz, 51Hz) in random order. The LED is flashed at a given frequency for a set period of time before it changes frequencies. Recordings where made with decreasing time periods (4s, 2s, 1s, 500ms, 300ms) at each frequency in order to determine the minimal time needed for the detection of the SSVEP signal at a given frequency.

Results

The data was analyzed using 200ms windows with 3/4 overlap. An untrained classifier was used in determining the frequency. SNR from multi-taper analysis was used for classification. At each time period, the classifier selected the frequency with the largest SNR. Data from a single EEG channel (O2 referenced to Cz) was used for initial classification. Frequency transitions spaced 300ms apart are easily distinguishable from a single channel with multi-taper analysis. 300ms transitions with 2bit choice yields a non-error corrected bit rate near 400 bits/min. The untrained classifier is able to determine the frequency of each window with 85% accuracy without any data preprocessing. Errors in classification primarily observed during the transition of frequencies and can be minimized with filtering. Discussion Having the subject attend to a single SSVEP stimulus minimizes subject error. Having the user focus on this simple task allows us to eliminate the possibility of subject error in choosing the flasher. Using a single flasher allows us to decouple the experiment from the users performance and allows us to find a maximal possible bit rate from SSVEP. Bit rates larger than 400bits/min may be possible with the use of higher stimulation frequencies.

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Keywords

SSVEP, BCI, Bitrate

M-2 Adaptive center-out paradigm for a four-directional BCI control

Dandan Huang*, Ding-Yu Fei, Ou Bai

Keywords: Brain-computer interface (BCI); Movement intention; Even-related desynchronization (ERD)/Event-related synchronization (ERS); Two-dimensional cursor control Background and Objective:

The study aimed to investigate the online performance of the BCI, using a two-dimensional center-out cursor control paradigm with a model adaptation method for better decoding of human movement intention from EEG activities, towards the development of a four-directional wheelchair control.

Methods

A center-out cursor control paradigm with a target on one of the four sides of a computer monitor was used. Three healthy subjects participated in a two-session study during a single visit: motor execution with actual physical movement and motor imagery. Each session contained a calibration step followed by 5 to 6 blocks of online validation. In the first session, the subject was asked to perform repetitive wrist extensions of right arm (‘RYes? or left arm (‘LYes? for 2.5s; perform repetitive wrist extensions for 1s and stop movement for 1.5s (‘RNo?for right arm, and ‘LNo?for left arm). In the second session, subject imagined that they performed the same motor task by motor imagery without overt movement. The EEG was recorded from 27 electrodes according to the international 10?0 system. The signal from 1.5s-2.5s after the cue onset was extracted for analysis. Computational models for classification were created by genetic algorithm based Mahalanobis linear discriminator (GA-MLD) using calibration data and tested through online validations. After each validation run, the model was updated using the entire calibration data and the past validation data to adapt potential learning process. Time-frequency and head topography plot were done for neurophysiological analysis of Even-related desynchronization (ERD) and Even-related synchronization (ERS). Validation performances were evaluated for both physical movement and motor imagery.

Results

The neurophysiological analysis showed that ERD and ERS occurred in beta band. ERD appeared during the movement or motor imagery on both hemispheres with emphasizes on one side and ERS appeared after movement or motor imagery on ipsilateral hemisphere. Offline classification provided 74.8?10.33% accuracy given by GA-MLD using 10-fold cross-validation method as an average performance of physical movement for three subjects; in case of motor imagery, offline classification result was 48.5 ?8.56%. Information transfer rate (ITR) was 32.16 bits per minute for physical movement and 24.24 bits per minute for motor imagery. In online validation, we observed a trend that overall performances increased across blocks for both physical movement and motor imagery; however, significant correlation was found only for motor imagery.

Discussion and conclusions

The successful classification suggests that ERD and ERS associated with movement intentions provided four distinguishable patterns for a four-category classification. The performance of the BCI can be robust during prolonged operation as revealed in the study. ITR has been significantly increased compared with that of the previous study (Huang et al., 2009). The proposed method can be adopted to develop an efficient brain-controlled wheelchair with high and robust performance. We will make further investigation on the robustness during multiple visits with larger populations.

M-3 Prestimulus SMR Amplitude ?a Key to Improve BCI Performance

Cecilia Maeder*, Claudia Sannelli, Stefan Haufe, Steven Lemm, Benjamin Blankertz

BACKGROUND AND OBJECTIVES

Recently, several studies investigated the ongoing brain oscillations preceding the presentation of a stimulus in perception as well as in motor and cognitive paradigms. In particular, the amplitude in the alpha frequency band is often correlated with performance. On the other hand, Dickhaus et al [1] developed an SMR-predictor, which shows a positive correlation of the sensorimotor rhythm (SMR) amplitude in a rest condition with BCI feedback performance. Bringing these threads together, we study the influence of pre-stimulus SMR on timing and strength of motor imagery induced SMR modulations with the aim to develop an SMR-state-dependent BCI.

METHODS

Data sets from 30 BCI naïve volunteers performing left and right hand motor imagery were investigated. Three spatial filters per class were calculated on the calibration data by Common Spatial Patterns (CSP) analysis and an LDA classifier was trained on the obtained CSP features. Trials of feedback data were analyzed separately in 2 groups according to pre-stimulus band power (high- and low-group). Feedback data were classified in sliding time intervals of 1000 ms duration as used, e.g., in cursor control.

RESULTS

On average, the classification error for the high-group was lower than for the low-group over the whole trial length. In particular, in the interval between 500 and 2500 ms after cue presentation, this difference was consistent in 21/23 subjects and highly significant ($p = .002$, Wilcoxon signed-rank test). Scalp patterns show for the high-group an ERD more localized to the contralateral hemisphere and, more prominently, a stronger ERS (idling) over the ipsilateral one.

DISCUSSION AND CONCLUSIONS

Trials with higher pre-stimulus SMR amplitude can be better classified than the ones with low amplitude. Interestingly, the difference in performance can be attributed to the ipsi- rather than to the contralateral hemisphere as can be concluded from the grand average ERD curves and the topological maps of r?values for left-right hand motor imagery. For this reason, it can be hypothesized that a better relaxation state of the sensorimotor system provides a better contrast for subsequent activation. . Furthermore, this effect occurs early after cue presentation (500 ms) and can thus be exploited for applications requiring faster decision making. In future work two approaches will be explored: 1) neurofeedback training will be used to increase users' SMR amplitude in order to take advantage of the faster and more accurate classification and 2) an SMR-state-dependent BCI will be developed to adapt the classification to the mental state of the user and thus improve the performance by adding this information.

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Keywords

EEG, pre-stimulus, SMR, BCI, classification performance, motor imagery.

M-4 Exploring the role of feedback in learning novel neuromotor mappings

Andrew Jackson*

Background and Objective

There exist two general paradigms within the BCI field. ‘Biomimetic?approaches aim to decode movement intentions from brain signals based on their relationship established off-line during natural movements. However, it is unlikely that activity within an injured motor system will exactly mirror the normal situation. Therefore, ‘biofeedback?approaches emphasize operant conditioning of new neuromotor associations driven by feedback during on-line operation. Accurate feed-forward control of a BCI requires an internal model to generate optimal neural commands for achieving any desired target state. As BCIs become more sophisticated, the dimensionality of control signals increases, but feedback is usually confined to a 2-d cursor space. Understanding how internal models of these redundant neuromotor mappings are acquired is vital for optimising BCI design in order to facilitate their ease of operation.

Methods

We are exploring these questions using a novel myoelectric-controlled interface (MCI) task. With the arm and hand immobilised, electromyogram signals recorded from multiple muscles control the position of a 'myoelectric cursor?in real-time. The mapping from muscle space to cursor space may be intuitive (muscles move the cursor in the direction that they act on the hand) or non-intuitive. Proprioceptive feedback is degraded by noise-modulated hand vibration. In this way we study motor learning under conditions in which the mapping from a high-dimensional control space to a low-dimensional feedback space can be precisely controlled and perturbed.

Results

Subjects are quickly able to acquire feed-forward control of a myoelectric cursor, even under non-intuitive mappings. Task redundancy is exploited by utilising multiple muscles to acquire each target. Tuning functions for individual muscles are cosine-shaped, as predicted by models of minimum variance in the presence of signal-dependent noise. Furthermore, the rate at which subjects learn the task is not dependent on accurate proprioceptive feedback. We are now investigating how subjects optimise their performance on the MCI task under a variety of conditions in which visual feedback is perturbed.

Discussion and Conclusions

We suggest that successful acquisition of internal models of novel neuromotor mappings involves learning the association between efference copy of central commands and peripheral feedback from the interface. The extent to which information about particular control signals is available to the brain is thus a critical factor in determining the degree to which subjects can acquire accurate control of unnatural interfaces such as BCIs and MCIs. Biofeedback experiments utilising different control signals can reveal how this efference copy is represented and utilised by the brain during learning. This knowledge should in future inform the design of improved BCI algorithms.

M-5 Attentional Manipulations can Enhance P300-based BCI Performance

Daniel Berry*, Chad Lakey, Eric Sellers

Background and Objectives

Severe motor disabilities such as amyotrophic lateral sclerosis (ALS) reduce or eliminate neuromuscular control and deprive affected patients of vital communication and control. Recent advances in noninvasive EEG-based BCIs have given patients new hope for communication and environmental control not provided by other assistive devices[1]. General lapses of attention, mind wandering, and lack of focus may all undermine BCI performance[2]. In a P300-BCI, non-target flashes are exogenous cues that could attract attention away from the endogenous task of attending to target item flashes. Thus, inducing a heightened state of attentional awareness and reducing distractibility may improve BCI performance. Mindfulness meditation and induction (MMI) offers such a possibility[3,4]. We expect MMI to have several important consequences for P300-based BCI use: one, it will focus attention to the target item; two, it will reduce distraction from non-target flashes; three, it will reduce P300 target latencies; four it will produce higher amplitude ERPs.

Methods

Using a 6x6 matrix row/column paradigm, performance was compared between subjects that participated in a meditative and mindfulness induction (MMI) and subjects that did not participate in the induction (NMI). The MMI consisted of a 6-min period in which the subject was guided through a meditative induction to obtain a state of attention and concentration that was then directed toward the computer screen[3,5,6]. Each group included seven subjects. Each session began with a no-feedback calibration period of 21 item selections. Stimuli were presented at a rate of 62.5ms with 62.5ms between flashes. For each item, every row and column flashed 13 times; thus, the target row and column flashed 26 times. Calibration data was used to derive a SWLDA[7] classifier used to provide online feedback for an additional 14 item selections.

Results

After 26 target flashes, online performance was 89% correct for the MMI group and 90% correct for the NMI group. Most importantly, offline analysis showed that after 10 target flashes accuracy for the MMI group was 82% compared to the NMI group 67%. In addition, there are indicators that the MMI may produce a different pattern of waveform morphology than the NMI condition. The positive peak around 200ms at electrode location Cz is larger for the MMI group than the NMI group. The negative peak at electrode location Pz is at 466ms, 30ms earlier than the NMI group, and the positive peak around 380ms at electrode location PO7 is larger for the MMI group than the NMI group. Additional data will be collected on approximately 20 subjects in each group.

Discussion and Conclusions

Although not statistically significant, after only 10 target flashes performance is 15% higher for the MMI group. Given the small number of data, this difference suggests that the MMI serves to focus and heighten attentional resources. In addition, the ERP data show larger component amplitudes at Cz and PO7 and shorter latencies at Pz. These initial results suggest that MMI training may improve P300-BCI performance.

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Keywords

BCI; P300 event-related potential; amyotrophic lateral sclerosis; EEG

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M-6 Practicing fast-decision BCI using a "goalkeeper" paradigm

Lenny Ramsey*, Michael Tangermann, Stefan Haufe, Benjamin Blankertz

Background and Objective

Brain-computer interfacing (BCI) aims at providing paralyzed patients with a communication device that obviates the need of using the usual motor pathways. Many BCI systems are based on motor imagery for encoding the user's intention. Motor imagery typically leads to event-related desynchronization (ERD) of the 10Hz mu-rhythm in the motor cortex associated with the respective limb. This EEG phenomenon can be used for control by a classifier that is individually trained on the subject's EEG [1,2]. We introduce the goalkeeper paradigm that aims at improving the speed of online BCI control.

Methods

Multi-channel EEG of 8 BCI-experienced subjects was acquired while they played 3 runs (100 trials each) of a BCI-controlled computer game that imitated the task of a goalkeeper during a penalty kick. During a trial a ball moved from the top of the screen towards one of its bottom corners. Using two different types of motor imagery (chosen from left hand, right hand and foot) the subjects controlled the horizontal movements of a bar at the bottom of the screen to catch the ball. Consistent with the goalkeeper metaphor, the bar could only be moved once, like a jump. The speed of the ball increased linearly from trial to trial and over the 3 runs. Subjects had to catch the ball within 2500ms, at the beginning of run 1, and 1250ms at the end of run 3. Late arrival in a correct corner or arrival in a wrong corner were interpreted as misses. The subjects were thus required to generate faster and/or stronger ERD responses in the later runs to steer the bar quickly into the correct corner. In an offline analysis, the goalkeeping performance, the reaction times and EEG features were analyzed in relation to the block design of the experiment.

Results

The goalkeeper paradigm effectively increased time pressure over the 3 runs. Performance was measured in terms of balls caught within the first 1250ms. 7 out of 8 subjects managed to respond with increased performance from run 1 to 3 (avg. of 33.8 balls caught in run 1 to 41.6 in run 3). A close analysis of time-frequency EEG features between successful trials of run 1 and 3 revealed different strategies of the subjects, e.g. earlier ERD or stronger ERD in the alpha band under time pressure. As a side effect, the training introduced for some subjects an additional ERD in the beta band (which had not been used for feedback). Earlier re-synchronization (ERS) could be observed for some subjects in run 3, where trials were shorter.

Discussion and Conclusions

The results of this study of eight subjects show that it is indeed possible to train people to respond faster to a stimulus using motor imagery. The changes in the brain signal which cause this increase in speed differ per person. To be able to assess how much faster people can really get and what the best strategy is to become as quick as possible a larger study needs to be conducted.

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Support

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Keywords

BCI, motor imagery, fast response

M-7 A 4-class brain-computer interface driven by mental strategies evaluated with and without user distraction

Elisabeth V. C. Friedrich*, Reinhold Scherer, Christa Neuper

BACKGROUND AND OBJECTIVE

One possibility for controlling a so called brain-computer interface (BCI) can be realized by detecting the changes in the rhythmic activity of the brain's electrophysiological signals (event-related (de)synchronization, ERD/S) by electroencephalography (EEG). Although motor imagery tasks are mostly used, the best strategy to modulate brain activity might be to use multiple mental tasks to better account for individual-specific differences. The aim of this study was first, to investigate to what degree four different mental tasks (mental subtraction, mental word association, mental spatial navigation and motor imagery) can be used to operate a 4-class BCI and second, to study whether participants retain satisfactory BCI control during distraction.

METHODS

This study included 7 right-handed volunteers who participated in ten 2.5-hour sessions over a period of 5 weeks. Users sat in front of a computer screen while EEG was recorded in 29 electrode positions. Each mental task was represented by a symbol in one of the corners of the screen. In every trial, one of the symbols was highlighted randomly and the user was asked to perform the associated task for 7s. First, 2 screening sessions, one without and one with distraction were recorded to set up the classifier. For classification common spatial patterns and Fisher's linear discriminant functions with majority voting were used. In the following sessions, continuous online feedback was provided in form of a bar graph as well as discrete feedback (reward) at the end of a trial each time the given mental task was detected correctly for a period >2s. In the last two sessions during the feedback period distracting tones were presented every second. Five 1 kHz and one 2 kHz tones were played in each trial in pseudorandom order. Users were asked to either ignore the tones or to react to the 2 kHz tone with button press.

RESULTS

Accuracies were based on the percentage of correct selections (rewards; i.e. the ability of maintaining the desired activation long enough for selection). The performance averaged over classes was significantly above chance level (p=0.25?.11) for all users. Single-session 4-class accuracies for 6 users reached over 60%, whereof 4 users achieved up to 68-72% accuracy. A repeated measurement ANOVA (class x session) indicated that motor imagery achieved highest correct detection rates (p<0.01). The number of session had no impact on performance (p=n.s.). Whereas, an ANOVA (class x condition of distraction: no tones, ignoring tones, reacting to tones) for the 9th session revealed higher accuracies in the 'ignoring tones' than in the 'no tones' condition ($p<0.05$), no such differences were found in the 10th session (p=n.s.).

DISCUSSION AND CONCLUSIONS

This study shows that it is possible to control a 4-class BCI from scratch using different mental strategies with accuracies that are significantly over chance level. The results furthermore suggest that users can maintain their performance during distraction, maybe even improve it under additional easy challenges (e.g. 'ignoring tones' condition). These results are encouraging for real-world application as all participants succeeded in operating the 4-class BCI even during distraction.

Keywords

Brain-computer interface, 4-class BCI, mental tasks, distraction

M-8 Auditory Semantic Conditioning in healthy and locked-in subjects: Thinking of “yes?and “no?

Carolin Ruf*, Adrian Furdea, Tamara Matuz, Daniele de Massari, Linda Van der Heiden, Jeremy Hill, Sebastian Halder, Boris Kotchoubey, Niels Birbaumer

Background and Objectives

Brain-Computer Interfaces (BCIs) provide the possibility to communicate for severely paralyzed people. As people in the complete locked-in state (CLIS) are not able to use current BCIs (Kübler & Birbaumer, 2008), there is a need for implementation of new learning paradigms that facilitate the achievement of BCI control for this population. Razran’s semantic conditioning (1939), which is based on classical conditioning, might represent a more suitable learning paradigm for people in CLIS because it does not require the so called goal-directed thinking. The aim of this study was to investigate whether semantically conditioned cortical responses can be used as a control signal for BCI, enabling basic YES/NO communication.

Methods

16 healthy subjects (Age 21-42, M = 25.13) and one subject with late stage ALS (amyotrophic lateral sclerosis) participated in the pilot study. EEG was recorded from 32 electrodes. The healthy subjects had two conditioning sessions on two consecutive days. The ALS subject had four conditioning sessions on four consecutive days within one week, this sequence being repeated three times. For conditioning, sentences with a true or false statement were presented in auditory modality and were immediately followed by aversive sounds. The participants were instructed to think “yes?after hearing a true statement and to think “no?after hearing a false one. True sentences were followed by pink noise and false sentences by white noise. In the first session, 300 sentences were presented, 50 of them were not paired with the unconditioned stimuli (pink and white noise). At the end of the second session (and in all following ones for the patient) 40 additional extinction trials were presented in which the sentences were not followed by the unconditioned stimuli (UCS). After each session, all subjects rated subjective valence and arousal of white and pink noise on the self-assessment manikin (SAM) scale.

Results

Assessment of arousal and valence of the unconditioned stimuli showed that the healthy subjects rated white noise significantly more aversive (higher arousal and more negative valence) as pink noise. The ALS subject’s ratings of white and pink noise were inconsistent over time. Stepwise linear discriminant analysis (SWLDA) was carried out for offline-classification of the cortical responses. In the classification SWLDA differentiated between a segment before the beginning of a new sentence (baseline) and a segment at the end of a sentence during the thinking of “yes?or “no? The classifier was trained on all trials with presentation of the UCS. Testing the classification on trials without the presentation of the UCS leaded to mean accuracies of about 78% for the healthy subjects and 57% for the ALS subject.

Discussion and Conclusions

The averaged evoked potentials show that auditory semantic conditioning of “yes?and “no?thinking is possible. SWLDA can differentiate between “yes?respectively “no?and a baseline, but not directly between thinking of “yes?and “no? We will carry out more tests on CLIS subjects to elucidate whether in this population the conditioned signal offers a suitable option for BCI based communication.

Support

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Keywords

BCI, EEG, Complete Locked-In, Semantic Conditioning, Communication

M-9 Psychological predictors of SMR-BCI performance

Eva-Maria Hammer*, Sebastian Halder, Benjamin Blankertz, Claudia Sannelli, Thorsten Dickhaus, Sonja Kleih, Klaus-Robert Müller, Andrea Kübler

INTRODUCTION

After about 30 years of research on Brain-Computer Interfaces (BCIs) there is little knowledge about the phenomenon that some people are not able to learn BCI-control. To elucidate this so called ‘BCI-illiteracy phenomenon? the current study investigated whether psychological parameters could predict performance in a single session with a BCI controlled by modulation of sensorimotor rhythms (SMR) with motor imagery.

METHODS

A total of 83 healthy BCI novices took part in the session. We used the machine learning BCI approach “Berlin Brain-Computer Interface?according to Blankertz and colleagues [1] which allows participants BCI control after a short run to calibrate the system to the individual brain pattern associated with motor imagery. Psychological parameters were measured with an electronic test-battery including clinical, personality and performance tests. The selection of tests was guided by theories of biofeedback learning, available studies on predictors of BCI performance, and clinical aspects influencing executive functioning. Predictors were determined by linear regression analyses.

RESULTS

Two psychological variables showed significant correlations with SMR feedback performance: (1) The output variable of the Two-Hand Coordination Test “overall mean error duration?(r = .26; p < .05) which is a measure for the accuracy of fine motor skills and for exactness of information processing. (2) The Attitudes Towards Work test variable “performance level?(r = .34; p < .05) which can be interpreted as degree of concentration. For predictor identification, we accomplished two simple linear regressions. The variable “overall mean error duration?accounted for almost 8 % of the variance in feedback performance (R?= .079; F1,78 = 6,718; p < .05). The “performance level?was also identified as a significant predictor which accounted for 13% of the variation in BCI performance (R?= .133; F1,38 = 5,83; p < .05).

DISCUSSION AND CONCLUSION

Psychological parameters seem to play a little but significant role for one-session performance in a BCI controlled by modulation of SMR. The influence of fine motor skills on motor imagery based BCI performance is in accordance with the idea that neurofeedback learning is similar to motor learning [2]. It is important to note that the BCI approach presented here relies mainly on pattern recognition and does not involve human learning, specifically not in the current study in which only one BCI session was performed.

Support

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Keywords

BCI, motor imagery, learning, psychological factors, executive function, predictors

N-1 Operant Modification of the Pain-related BOLD-Response in Healthy Controls using a Brain Computer Interface (BCI)

Herta Flor*, Mariela Rance, Michaela Ruttorf, Frauke Nees, Pinar Yilmaz

Background and objectives

Previous work by deCharms et al. (2005) showed that feedback from the rostral anterior cingulate cortex (ACC) during painful thermal stimulation can increase or decrease pain perception. We used a mechanical stimulus in an operant conditioning paradigm where subjects learned to selectively regulate the BOLD effect in the ACC in a functional magnetic imaging session.

Methods

In two localizing sessions painful mechanical stimuli were applied to the second digit of the left hand of five subjects followed by subjects imagining painful stimuli making it possible to pinpoint ACC. In the first session subjects tried to up-or down-regulate BOLD activity in the ACC while they received visual feedback in the form of a moving ball. In the following 4 sessions painful stimuli were applied and subjects tried to move the ball either up or down indicated by an arrow. Pain intensity and unpleasantness were rated after each session.

Results

All subjects were able to selectively increase the BOLD effect in the ACC compared to a control region based on feedback. Decrease of the BOLD effect was not possible in the number of sessions we used. Up-regulation of the BOLD effect in the ACC did not lead to increased ratings of pain intensity or unpleasantness.

Discussion and conclusions

These results are in contrast to the findings of deCharms. To improve learning effects, more and longer training sessions will be introduced. Moreover, we will compare ACC feedback with that from the insula to determine if better pain control is possible. Finally, we plan to use a successful design also in patients with chronic pain.

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Support

Supported by the European Research Council.

Key words: fMRI, pain, ACC

N-2 Application of a video feedback based BCI for phantom pain - a case study

Armin Walter*, Alexander Roth, Georgios Naros, Niels Birbaumer, Alireza Gharabaghi, Wolfgang Rosenstiel, Martin Bogdan

Background and objective

A 63 year old male with phantom pain attacks after amputation of his right arm took part in a study on BCI and epidural electrical stimulation for pain reduction. He was able to report positions and perform imaginary movements of his phantom arm and hand. After implantation of an ECoG grid, he trained for nine days with a BCI giving visual feedback of the attempted phantom movements to the patient. Our goal was to show that the patient is able to gain control of this system, thus enabling a new approach for phantom pain therapy.

Methods

We recorded data from a 64 channel ECoG grid centered on the hand knob of the left M1 and EMG from bipolar electrodes on muscles on the stump and the left arm with a sampling rate of 1000 Hz. Two initial screening sessions with 50 trials of cued finger extensions of the phantom hand two days after implantation of the grid were used to select features for the classifier. Based on this data, we chose 3 channels that showed strong synchronisation in high frequencies during the movement phase. The general purpose BCI application BCI2000 was used for signal processing, classification and controlling the video application via UDP. We employed the CursorTask paradigm with 50-170 trials per session. In each trial, the patient was cued to extend the fingers of his phantom hand for 5 seconds followed by 8 seconds of rest. If the output of the classifier was positive (corresponding to a detected high power in the 120-150 Hz band for the three electrodes) for 200 ms, a video of extending fingers was started. If the output was negative for 200 ms, the video was paused.

Results

We tested three different performance measures to evaluate whether the patient gained control of the BCI system. To obtain a baseline performance level, 30 minutes of unrelated ECoG data were fed into the video feedback system. The percentage of trials with video movement increased from 70% in the first session to 100% in the last two sessions with a baseline performance level of 60%. No clear trend was observed for the percentage of video movement during a trial and the average length of consecutive video movements. Both did not differ significantly from the baseline level.

Discussion and conclusions

We conclude from the strong positive trend of the first performance measure over time that the patient was able to gain control of the video feedback BCI driven by attempted extensions of the fingers of his phantom hand. We think that the missing trend in the other two measures is due to the patient being only able to maintain the phantom movement for a constant amount of time. Future studies with phantom pain patients can use the video feedback BCI to provide visual feedback for attempted phantom limb movements which may lead to pain reduction by inducing plasticity in the corresponding brain area.

Support

This work was supported by the European Union (ERC 227632).

Keywords

BCI, electrocorticography, phantom pain, video feedback

O-1 Emotion BCI: Communicating emotion via EEG dynamics

Scott Makeig*, Julie Onton

Background and Objective:

So far the brain-computer interface (BCI) field has focused in large part on developing abilities to make one or more discrete choices (yes/no, on/off, left/right, etc.) and to use written language (spelling out words). Yet our sense of personal fulfillment derives not only from this kind of agency and communication. Many of our most deeply felt and influential experiences involve communication with others by gestures, facial expressions, eye movements and nonverbal sounds. Inability to fluently communicate feeling to others burdens not only locked-in patients but also many other physically and mentally handicapped subjects (stroke, palsy, Alzheimer's, etc.). Is it possible to interpret EEG dynamics to learn what a subject is feeling? And if so, could we use EEG to communicate our feelings to others?

Methods

Onton & Makeig (Front. Hum. Neurosci., 2009) explored the first of these questions by using a method of guided imagery to induce 32 eyes-closed subjects to imagine situations in which they would feel a series of 15 suggested emotions while attending to their somatic sensations to intensify their emotional experience. Subjects pressed a hand-held thumb button when they first felt the indicated emotion and then attempted to hold the feeling as long as possible. When the experience waned, they pressed the button again, cueing delivery of relaxation instructions, followed by the next emotion suggestion. In a de-briefing survey, subjects generally indicated that they experienced most of the suggested emotions moderately to strongly. This gave us 256-channel EEG data from 15 labeled 1-5 min emotion periods per subject.

Results

We looked for within-subject differences in EEG dynamics during these periods by performing (temporal) independent component analysis (ICA) followed by (spatial-log-spectral) ICA on the independent brain source process activities. The latter found multiplicative spectral modes each characteristic of one or more source process. These independent modulator processes included a large class of broadband high-frequency processes scaling power from near 30 Hz to 200 Hz or higher. Multidimensional scaling of mean broadband power levels during the 15 periods in the individually processed data from the 32 subjects returned a two-dimensional 'emotion space' in which one dimension loaded strongly on emotional valence. Further, even a few seconds of data removed from each emotion period could be assigned its original emotion label in most instances by comparing its dynamics to those of the remaining data from the same subject.

Discussion and Conclusions

The first author proposes to test, next, whether this data modeling method can be applied to musician subjects who imagine different notes of the scale by imaginatively experiencing their emotional or affective nature. If so, can we build a musical emotion BCI that allows musical subjects to select and play notes of the scale (slowly, but with 'heartfelt' intent) by EEG alone, thus producing a sense of emotional communication. We will show pilot data from experiments toward this goal, and plan to use the resulting system to direct the first public performance of an original 'concerto for brain and small chamber orchestra.?If successful, more general emotional BCIs might be developed for use by normal and handicapped subjects.

O-2 BCI for psychometric assessment

Paolo Perego*, Giuseppe Andreoni

Background and Objectives

During the last two decades many efforts were dedicated to BCI reliability improvement in several applications, from research [1], to home and assistive technology [2]. However few clinical experiences were carried out. The aim of our study is to create a new BCI-based protocol for psychometric assessment when alternative evaluation is impossible because of the severity of motor impairment.

Methods

We designed a Raven Progressive Coloured Matrix (Raven PCM) test through a SSVEP BCI system taking care that the BCI must not interfere with the final result of the psychometric test. This allowed us to use the validation already presented in literature [3]. The Raven PCM is a test composed by three sections each of twelve tasks. Each task consists in choosing the missing item in a figure among six available choices. Each section of the Raven test is designed to test cognitive functions. We built a software version of the classic paper Raven PCM test using the framework BCI++ [1] and to be used with our - already validated - four command SSVEP BCI [1]. The software records: answers, time for single answer, error number and number of moves for each selection (Fig 1). The classic paper Raven PCM differs from our BCI based test in three main points: 1. The six possible answers are presented at the same time and not sequentially. 2. The background is white while in our software is grey to increase the contrast when using visual stimulation 3. During the choice, the actual selection is highlighted zooming the corresponding image. We tested if these differences can interfere with the performance in the cognitive task. A first test on a group of ten healthy subject without previous BCI experiences was carried out using a specific protocol that can be divided into six parts (Fig 2): 1. Screening: to identify the best stimulation frequencies for the subject. 2. Training: to configure and train the classifier for the identification of the commands. 3. Testing: to validate and confirm the configuration parameters and test the system performances 4. Game: to train the subject to use BCI system without stressing with difficult tasks. 5. Match: to train the subject to use the selection method described above with a simple matching test. 6. Raven: to test the subject with the 36 Raven PCMs. The first three steps are necessary to calibrate the system [1]. The fourth and fifth phases are required to learn the subject using both the BCI and the selection method. During the test we set three inclusion criteria: - The subject can elicit SSVEP signal; - The subject can complete test with a good bit-rate - The subject can understand and control the method of selection for Raven test. This last inclusion criteria is very important when the Cognitive test is administered to disabled people (eg. PCI, spastic paraparesis). The subject can perform the test only if all criteria are respected.

Results

Nine out of ten subjects showed the SSVEP response and completed the whole protocol. Raw data (Tab 1) shows that the bit-rate [4] affects the duration of the Raven PCM test and the number of moves but not the results .

Discussion and Conclusion

Our study demonstrated that BCI can be used for the administration of cognitive test. The software can be easily adapted to other BCI paradigms (eg. P300 and Motor Imagery). Next step will be the comparative tests between healthy and disabled people with different cognitive tests.

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Keywords

Brain Computer Interface (BCI), SSVEP, psychometric assessment, Raven test. Fig1: pperego.altervista.org/figure1.jpg Fig2: pperego.altervista.org/figure2.png Tab1: pperego.altervista.org/Table.png

O-3 Reliable Detection of Emergency Braking Situations during Simulated Driving

Stefan Haufe*, Matthias Treder, Max Sagebaum, Manfred Gugler, Arne Ewald, Klaus-Robert Müller, Gabriel Curio, Benjamin Blankertz

BACKGROUND AND OBJECTIVE

Mental state monitoring is of particular interest in safety-critical applications such as car driving. In emergency braking situations, for example, human reaction is often limited due to inattentiveness, slow cognitive processing, motor inabilities or simply hesitation. The aim of the present study is to identify typical electrophysiological and behavioural markers already occurring prior to emergency braking.

METHODS

We conducted a driving simulator study (N=20) using a customized version of the open-source racing software TORCS [1]. The experiment comprised 3 blocks (45 minutes each) of driving, in which the subjects had to tightly follow a computer-controlled car at a speed of 100km/h. While subjects were within the desired maximal distance of 20m, the preceding car occasionally (20-40 seconds ISI, randomized) performed sudden brakings, forcing the subject to immediately brake as well in order to avoid a crash. From the first half of the experiment, we extracted ERPs, EMG and the deflection of the throttle pedal in order to train a series of classifiers to detect emergency braking intentions. These classifiers were optimized to provide decisions at different stages of intention build-up prior to braking onset. The level of predictive information attained at each stage was assessed in the second half of driving, where the task was to distinguish about 100 genuine emergency braking events from approximately 38,000 examples of uncritical situations sampled from the inter-stimulus intervals in steps of 100ms. Classification performance was measured in terms of the True Positive Rate (TPR) for a fixed FPR of 0.01% (maximally three false alarms in total), as well as the AUC score. The results were compared to those of classifiers operating entirely on either neurophysiological or behavioural features.

RESULTS

Various ERPs predictive of emergency braking occasions could be observed between the initial flashing of the preceding car's brake light and the onset of braking: an N1 related to low-level visual processing of the brake light stimulus and a P300 reflecting the rareness and importance of this event. Further, a strong readiness potential (BP), building up before the actual movement. The use of these features allowed reliable classification, as evidenced by average AUC scores exceeding 0.7 and 0.9 as early as 400ms and 200ms before braking onset, respectively . Addition of EMG- and throttle-derived features led to consistent further improvement, because these modalities capture the characteristic change from throttle to braking pedal. Between 300ms and 200ms prior to braking (the average EMG onset being at 270ms), the average TPR increased from 5% to 25%.

DISCUSSION AND CONCLUSIONS

All the observed ERP's occur frequently in normal driving situations. However, our analysis shows that their co-occurrence in conjunction with a rapid foot movement robustly characterizes certain emergency situations. A detector based on these findings could be integrated in driving assistance systems to initiate belt tightening devices and measures to optimize the car dynamics for potentially upcoming crashes. In the future, we intend to validate our results in an online study.

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SUPPORT

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KEYWORDS

Driving Assistance, Emergency Braking, N1, P300, Readiness Potential

P-1 Causal Influence of Gamma Oscillations on Performance in Brain-Computer Interfaces

Moritz Grosse-Wentrup*, Jeremy Hill, Bernhard Schölkopf

Background and Objective:

While machine learning approaches have led to tremendous advances in brain-computer interfaces (BCIs) in recent years (cf. [1]), there still exists a large variation in performance across subjects. Furthermore, a significant proportion of subjects appears incapable of achieving above chance-level classification accuracy [2], which to date includes all subjects in a completely locked-in state that have been trained in BCI control. Understanding the reasons for this variation in performance arguably constitutes one of the most fundamental open questions in research on BCIs.

Methods & Results

Using a machine learning approach, we derive a trial-wise measure of how well EEG recordings can be classified as either left- or right-hand motor imagery. Specifically, we train a support vector machine (SVM) on log-bandpower features (7-40 Hz) derived from EEG channels after spatial filtering with a surface Laplacian, and then compute the trial-wise distance of the output of the SVM from the separating hyperplane using a cross-validation procedure. We then correlate this trial-wise performance measure, computed on EEG recordings of ten healthy subjects, with log-bandpower in the gamma frequency range (55-85 Hz), and demonstrate that it is positively correlated with frontal- and occipital gamma-power and negatively correlated with centro-parietal gamma-power. This correlation is shown to be highly significant on the group level as well as in six out of ten subjects on the single-subject level. We then utilize the framework for causal inference developed by Pearl, Spirtes and others [3,4] to present evidence that gamma-power is not only correlated with BCI performance but does indeed exert a causal influence on it.

Discussion and Conclusions

Our results indicate that successful execution of motor imagery, and hence reliable communication by means of a BCI based on motor imagery, requires a volitional shift of gamma-power from centro-parietal to frontal and occipital regions. As such, our results provide the first non-trivial explanation for the variation in BCI performance across and within subjects. As this topographical alteration in gamma-power is likely to correspond to a specific attentional shift, we propose to provide subjects with feedback on their topographical distribution of gamma-power in order to establish the attentional state required for successful execution of motor imagery.

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Keywords

Motor imagery, sensorimotor-rhythm, gamma oscillations, causal inference, EEG

P-2 The first trial use of BCI2000 at home in Japan

Sachiko OKA*, Koichi Mori, Toshinori Maruoka

Background Although brain computer interface (BCI) research has been rapidly expanding in Japan, its usefulness has not yet been demonstrated at home, while that of BCI2000 has been for several years in US (Vaughan et al, 2006). Because many of those with severe disabilities choose to live at home even with mechanical ventilation in Japan, it is all the more important to test the BCI in their own home to be really beneficial to them.

Methods

The participant of the current paper was 59 year old man, who had been diagnosed as ALS for 12 years, and had been on mechanical ventilation for 8 years. He had been using a switch operated scanning character input device (Den-noshin, Hitachi, Japan) for 7 years. His eye blinks were present but involuntary, and informed consent was obtained with his eye movement to the right, which is the direction he could voluntarily and rapidly control. The 17?or 19?LCD monitor for stimulus presentation was held 70-cm from the subject’s eyes. Vamp-16 (Brain Products) was used for EEG recording, with 8 active channels at the first visit, and several more at the second visit. P3speller of BCI2000 was exclusively used. The patient was instructed to count the number of flashes of the intended input character in a 6x6 matrix. The same sequence was repeated for 16 characters, and the correct estimation rate was computed. The recorded EEG data were analyzed by P3Classifier (BCI2000) to generate patient's personal discrimination data, which was used in the next spelling session. The final free spelling session was with a 7x10 Japanese character matrix.

Results

Power line noise was comparable as in the laboratory, and could be filtered out with the built-in filter of BCI2000. At the first visit, the P300 was very small, and the correct answer rate was 6.25% online, and 18% for offline analysis. In order to improve the P300 generation, the communication device was disconnected from the forehead tension-sensor switch and distraction was kept minimum at the second visit. Then clear P300 was observed, and the correct answer rate rose to 43.75% online (15 averages), and 91% offline (6 averages). In the free spell session, the first two letters of the total of 4 letters in a word that the patient wanted to spell was correct. The decline of the accuracy might be at least partially due to the extreme fatigue of the patient, having worn the electrode cap for nearly 3 hrs at the second visit Conclusions BCI2000 was proven useful in constructing the home BCI system rapidly without involving any programming for a Japanese ALS patient under mechanical ventilation. However, the home environment has its own problems that drastically reduce BCI performance, which need to be addressed by experienced experimenters. Other areas of necessary development include the establishment of training courses for the home operator of BCI2000, and the legislation to support the distribution of the cutting edge communication aid at home.

Q-1 BCI for Rehabilitation: Goal Oriented Imagination and Test of Vividness of Motor Imagery

Aleksandra Vuckovic*

Background and Objectives

Motor imagery is a well established technique among professional sportsmen, dancers and musicians helping them to improve quality of skilled movements. Motor imagination is also an often used strategy for Brain Computer Interface (BCI), but the purpose of BCI is to help patients to communicate with their environment, not to improve quality of movements. Therefore little attention is paid on the exact type of imagery and BCI participants are not tested for vividness of their imagery. Neurofeedback provided through BCI offers an excellent opportunity to re-train Central Nervous System after an injury such as spinal cord injury or stroke. In BCI used for motor rehabilitation imagination should be used for practicing goal-oriented activities of daily living. BCI could be used with a visual feedback or to voluntary control a device used in a functional electrical therapy. The objectives of this study were to determine:1 Whether there is a correlation between a vividness of kinaesthetic imagery and the output of a two class classifier used for BCI. 2. Influence of a real goal of action on the quality of imagination, as assessed by a BCI.

Methods

Eleven able-bodied, right handed, naive volunteers participated in the study. Their vividness of visual and kinaesthetic imagery (VVI and VKI) were tested using [1,2]. Questionnaires had 17 questions and 5 grades for each answers, ranging from 'no imagery?to 'imagery as clear as doing/seeing? Experimental procedure described in [3] was adopted for off-line classification using Biosig software. Features were logarithmic band powers in predefined frequency bands and linear discriminate analysis was used to classify between the left and the right hand. Volunteers were asked to: 1. Hold a mug; 2. Imagine to hold a mug with their palms facing the table and having a mug on a table, in volunteers?peripheral visual filed; 3. Imagine to hold a mug without a presence of a real mug. Conditions were separated in different sessions and the order of the sessions was semi-random.

Results

Kinaesthetic imagery was in a range of 40 to 76 points. In case of imagination without a presence of an object the average classification error was 31.7 ? 3.9 % (min 25.1, max 36.0) and there was a strong linear correlation between the results of VKI and the classification accuracy (Pearson test R=0.8144, P=0.0023) Classification error decreased for goal-oriented imagination (27.5? 3.9 % , min 23.0, max 32.0). Classification accuracy improved more in people with lower VKI scores resulting in no correlation between the test and BCI output (R=0.3342, P=0.3152). There was a strong correlation between VVI and VKI (R=0.9198, P=0.002)

Discussion and Conclusion

Results of this study showed that motor imagery test can be used as an indicator whether a person is a good candidate for BCI. Presence of an object improved persons?ability to imagine, that is of relevance should BCI be used in rehabilitation. Strong correlation between VVI and VKI indicates that VVI can be used to test patients with a loss of kinaesthetic sensations.

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Keywords: BCI, vividness of motor imagery test, object oriented imagination, motor rehabilitation

Q-10 Motor imagination combined with peripheral stimulation increases cortical excitability

Signe Kristensen*, Natalie Mrachacz-Kersting, Johnny Nielsen, Thomas Sinkjær, Dario Farina

BACKGROUND AND OBJECTIVE.

Electroencephalogram (EEG)-based Brain-Computer Interface (BCI) technologies use brain signals to control external devices to supplement impaired muscle control or to increase the efficacy of rehabilitation therapies [Daly JJ, Wolpaw JR. The Lancet:Neurology,7:1032-1043,2008]. The plasticity of the human motor cortex plays an important role in functional recovery after stroke and it is known that repetition of a simple motor task can reorganize the motor cortex [Classen J et al. J Neurophysiol.1998Feb;79(2):1117-23]. However, acute stroke patients may not be able to move the affected limb, thus classic exercise therapy may not be viable. This study investigated a novel approach for changing the excitability of the cortical projections to the tibialis anterior (TA) muscle, consisting of repetitions of concurrent motor imagination and peripheral stimulation. It was hypothesized that the concomitance between the cognitive process of movement (motor imagination) and the ascending volley due to the peripheral electrical stimulation would increase cortical excitability.

METHODS

Preliminary experiments were conducted in 3 subjects. First, the movement-related cortical potentials (MRCP) were measured at the location Cz while the subjects performed 50 imaginary ankle dorsiflexions with their right foot, spaced by 5-7 s. A visual interface provided the cue for the subjects on when to start the motor imagination. From the average MRCP, the preparation, execution and post-execution phases were identified. During the following interventions, subjects were again asked to imagine a dorsiflexion movement, again receiving feedback on the onset of the motor imagination. However, during each motor imagination, an electrical stimulus was applied to the deep branch of the common peroneal nerve at motor threshold. The timing of the peripheral stimulation was such that the afferent volley arrived at the cortex during either the preparation phase (intervention 1(INT1)), the execution phase (intervention 2 (INT2)) or post the execution phase (intervention 3 (INT3)). The three interventions were separated by more than 3 days and the sequence of the interventions was randomized for each subject. Motor evoked potentials (MEPs) were elicited in the TA by transcranial magnetic stimulation before and after each intervention. The change in TA MEP size was used to assess changes in cortical excitability.

RESULTS

The preliminary results on the 3 subjects tested showed the largest increase in the MEP size for INT1 (average over the three subjects, 143%), whereas the increase was less for INT2 (118%) and further reduced for INT3 (107%). When the same protocol was repeated without peripheral electrical stimulation, motor imagination alone determined an increase in MEP size of 112%.

DISCUSSION AND CONCLUSION

The results support the hypothesis that the combination of motor imagination and peripheral stimulation increases cortical excitability to a greater extent than motor imagination alone. Moreover, the increase in cortical excitability was found to depend on the timing of the arrival of the electrical stimulation with respect to the cognitive state. These observations indicate the potential use of combined motor imagination and electrical stimulation as a new neuro-rehabilitation strategy. However, these preliminary results should be substantiated on a greater number of subjects to validate the hypothesis.

Q-2 Conditioning of cortical responses to the trueness and falseness of word pairs: a new paradigm for basic communication by means of BCI

Linda Van der Heiden*, Adrian Furdea, Tamara Matuz, Carolin Ruf, Daniele de Massari, Sebastian Halder, Piotr Jaskowski, Niels Birbaumer

Background and Objective

Over the last decade it has been repeatedly shown that patients with sever physical impairment (paralyzed patients with residual control over some muscles) are able to communicate or control a brain computer interface (BCI) (Kübler & Birbaumer, 2008). In different neurological diseases, such as amyotrophic lateral sclerosis (ALS) the neuronal degeneration may progress such that patients develop the so called completely locked-in state (CLIS), in which they have no control over their muscles. There is a lack of published data of patients in CLIS being able to communicate by means of a BCI (Kübler & Birbaumer, 2008). Only one group in Japan (Naito et al. 2007) was able to classify between 'yes?and 'no?via discrimination between active (brain calculations) and rest states of the brain using near infrared spectroscopy (NIRS). It has been suggested that a paradigm shift from instrumental-operant learning to classical conditioning could overcome the failure of completely locked-in patients to achieve BCI communication (Birbaumer, 2006). The main objective of the present study was to investigate the applicability of an auditory semantic classical conditioning paradigm within a BCI setting to enable basic yes/no communication.

Methods

The paradigm consisted of two phases: acquisition and extinction. In the first block of the acquisition phase, 50 congruent and 50 incongruent auditory word pairs were randomly presented (e.g. 'animal-elephant?or 'animal-Germany?. The conditioned stimuli (CS) comprised thinking on either "yes?or "no? according to the type of the word pair. We used two different unconditioned stimuli (UCS) for "yes?and "no?conditioning: a segment of baby laughter - immediately following a congruent word pair and a metal scrapping - following an incongruent word pair. In the next two blocks, one of every 10 CS, respectively, one of every 5 CS, at random, was not paired with the UCS. The extinction block consisted of 40 unpaired word pairs. The electroencephalogram (EEG) and electrocardiogram (ECG) of 16 healthy subjects (age 21-45) have been continuously measured during these blocks.

Results

Results of the Self Assessment Manikin (SAM) test showed that the participants reported more negative valence and a higher arousal for the metal scrapping sound compared to the baby laughter. The preliminary results show differentiable evoked cortical responses between the averaged EEG segments at the beginning of the word pair and during the UCS. This was true for both congruent and incongruent word pairs. Using the stepwise linear discriminant analysis (SWLDA), classification accuracies between 80 and 95% were found. For the unpaired word pairs (not followed by a UCS), discrimination between the averaged EEG segments at the beginning of the word pair and right after the word pair was possible with accuracies ranging between 58 and 89%.

Discussion and Conclusions

This pilot study shows that conditioned evoked responses for ‘yes?and for ‘no?thinking can be identified and classified offline. Thus, the proposed paradigm has the potential of being used to restore or maintain basic yes/no communication in CLIS patients. However, further work and improvement are needed to test for online accuracy.

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Q-3 First Steps towards a Motor Imagery Based Stroke BCI

Vera Kaiser*, Alex Kreilinger, Gernot Mueller-Putz, Christa Neuper

BACKGROUND AND OBJECTIVES

Recent approaches in Brain-computer interface (BCI) research aim at developing a BCI for clinical rehabilitation to recover motor function e.g. after stroke [1]. At all stages of stroke recovery, the mental rehearsal of movements (motor imagery) can induce activation of sensorimotor networks that were affected by lesions [2]. By using a BCI, the patient’s progress and compliance in performing MI can be monitored and appropriate patterns are reinforced by providing the patients with feedback. Using BCI as a tool for feedback training requires a fast and easy acquisition of a reliable classifier to detect the appropriate activation patterns. The usual practice for training a classifier is to record EEG during MI without giving feedback and use this data to calculate a classifier. For a stroke BCI feedback training it would be advantageous if we could give appropriate feedback from the beginning. Hence, new strategies for setting up a classifier are needed. As is known from previous work the activation patterns (event related desynchronization ERD) of the sensorimotor cortex during active and passive movement and during MI are quite similar [3, 4]. Therefore, it should be possible to use data from active or passive movement to set up a classifier for the detection of MI. We already know that it is possible to use data from foot motor execution to set up a reliable classifier for the detection of foot MI [5, 6]. In this study we explore, whether a similar strategy could be applied to data from active and passive hand movements in a group of elderly persons.

METHODS

EEG was recorded from three Laplacian channels over the sensorimotor cortex (C3, Cz, C4) in a sample of 20 healthy elderly volunteers. Participants performed three different tasks, passive hand movement (performed by a hand robot, Tyromotion, Graz Austria), active hand movement and hand MI. Classifiers (task against rest) were calculated with data from every task by means of a linear discriminant analysis. Relevant features were selected with distinction sensitive learning vector quantization [7]. In the next step the calculated classifiers were used to detect ERD in offline MI data.

RESULTS

The mean performance of the classifiers in detecting MI against rest was above random, from 63% up to 71%. The performance of classifiers calculated from passive and active hand movement data did not differ significantly from the performance of classifiers calculated from hand MI data ($F(2/28) = 2.32$; n.s.) regarding the classification accuracy for detecting MI.

DISCUSSION AND CONCLUSION

In this study, we have shown that it is possible to use classifiers calculated with data from passive and active hand movement to detect MI. The advantage of this approach is that passive and active movements are part of the normal stroke rehabilitation. For working with stroke patients, a physiotherapy session would be used to obtain data for classifier setup and the BCI rehabilitation training could start immediately. In a next step, we want to test this approach in stroke patients. First sessions with patients will start shortly.

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Keywords

Stroke rehabilitation, motor imagery, passive movement, motor execution, Brain-Computer Interface, classifier setup.

Q-4 Are stroke patients capable of operating non-invasive EEG-based motor imagery brain-computer interface?

Kai Keng Ang*, Cuntai Guan, Karen Sui Geok Chua, Kok Soon Phua, Chuanchu Wang, Haihong Zhang, Zheng Yang Chin, Rongsheng Lin, Beng Ti Ang, Christopher Kuah

Background and Objective

Recent advances in brain–computer interface (BCI) technology hold promise to stroke survivors by enabling the interaction with their environment through brain signals rather than through muscles, and restoring motor function by inducing activity-dependent brain plasticity. The objective of this paper is to investigate the extent of detectable brain signals in a larger population of stroke patients for operating a non-invasive EEG-based motor imagery BCI.

Methods

EEG data is collected from sub acute and chronic patients recruited from a neurorehabilitation facility linked to a local hospital with an acute stroke unit. 52 stroke patients and 16 healthy subjects have been recruited for the study. 8 stroke patients performed finger tapping using the stroke-affected hand. 44 stroke patients performed motor imagery using the stroke-affected hand as they are not able to perform finger tapping with the stroke-affected hand. 16 healthy subjects performed motor imagery of left hand. Trials of EEG data are collected from each subject whereby each trial involved a preparatory time of 2 s, a visual cue to perform a left or right action for 4 s, and at least 6 s of rest. The EEG data from finger tapping or motor imagery and background rest condition are extracted 0.5 to 2.5 s and -2.5 to -0.5 s from the onset of the visual cue respectively. The subjects are instructed to minimize physical movement and eye blinking throughout the EEG recording process except during the rest period. 10^10-fold cross-validations are performed using the Filter Bank Common Spatial Pattern (FBCSP) algorithm on trials of EEG data that comprised 80 trials of the respective action and 80 trials of background rest, and the classification accuracies of all the subjects are then analyzed.

Results

The 95% confidence estimate of the accuracy on the respective action at chance level is approximately 0.43 to 0.58 using inverse of the binomial cumulative distribution function. The results show that mean accuracies of motor imagery by healthy subjects (u=0.81) is significantly better than motor imagery by patients (u=0.72, p=0.0098), but not significantly different from finger tapping by patients (u=0.80, p=0.94) using two-sample t-test. There is no significant difference between the accuracies of detecting motor imagery or finger tapping by patients (p=0.051). In addition, 6 out of 44 patients and 1 out of 16 healthy subjects performed motor imagery at chance level.

Discussion and Conclusions

This study showed that the averaged accuracy in detecting motor imagery of stroke-affected hand of patients is 72%, albeit lower than the accuracy of 81% in detecting motor imagery of left hand by healthy subjects. Nevertheless, 86% (38 out of 44) of the patients could operate motor imagery BCI better than chance level. Hence this study showed that brain signals from stroke patients could be detected for the operation of non-invasive EEG-based motor imagery BCI.

Keywords

Motor Imagery, Brain-Computer Interface, Stroke, Common Spatial Pattern

Q-5 Usable Signal From Involved Stroke Hemisphere For Combined BCI/FES or Combined BCI/Robot and Initial BCI Session Accuracy

Kenneth Hrovat*, Janis Daly, Roger Cheng, Jean Rogers, Krisanne Litinas, Mark Dohring

Background and Objective

We tested a brain computer interface (BCI) system for use by stroke survivors for upper limb motor learning. There is very little in the literature attesting to whether stroke survivors can use BCI signals generated from attempting to perform the very motor tasks that are impaired. Also, there is very little evidence regarding whether stroke survivors can gain control of brain signal within a few sessions of BCI use. Both of these capabilities would be required in order to practically utilize a BCI system as a method for producing motor recovery after stroke. Hypothesis 1: Healthy adults and stroke survivors could attain accurate control of the brain signal by using imposed motor tasks, that is, the very motor tasks that are impaired after stroke. Hypothesis 2: Stroke survivors will be able to attain sufficient accuracy of brain signal at initial sessions so that the brain signal can be used within a few weeks for motor-relearning purposes.

Methods

We enrolled 2 healthy adults, and 5 stroke survivors with impaired upper limb motor control (>6 mos). Scalp EEG was acquired using a SynAmps2(Compumedics, El Paso, TX) amplifier system and an Electro-Cap (ECI, Eaton OH) with 58 monopolar channels referenced with linked earlobe electrodes. The signal was sampled at 250Hz and bandpass filtered from 0.1 to 60 Hz. We used the BCI2000 software (Wadsworth Research Lab; Albany, NY, USA) for the brain signal screening and brain signal training. We modified the BCI2000 graphical user interface and added an external trigger signal output capability using a Digital Output card added to the computer, configured to provide a trigger to activate the surface FES device for BCI+FES wrist/hand training. The robot was triggered through a network link. The robot was used for BCI+FES shoulder flexion and elbow extension training in a horizontal plane (InMotion 2 Shoulder/Elbow Robot; Boston, MA, USA). A Universal External Control Unit (UECU; DVA FES Center, Cleveland, Oh, USA) was configured by our team to provide surface FES. Robot or FES was triggered after the integrated brain signal passed a specified threshold. FES parameters were: 0-80Hz, 255 microsecs pulse width, and amplitude within a comfortable range. Measures were accuracy of brain signal control during imposed motor tasks: either shoulder/elbow or wrist/hand tasks that were 1) imagined or 2) attempted, as well as 3) imposed relaxation of muscles. Initial session accuracy for each condition was generated. Subjects were screened and provided with 9 training sessions (3 times/week).

Results

For BCI use of imposed tasks, for the healthy adults, there was high brain signal control accuracy for the imposed task of imagined shoulder/elbow reach (>80% accuracy), and for the imposed task of “relax the muscles? there was a brain signal control accuracy of >85%. For the shoulder/elbow motor task, imagined, stroke subjects were able to control brain signal activation during the imagined trials at a mean accuracy rate > 84%. For the relax task, brain control accuracy rate was less than chance, < 50%; these data are understandable in light of the observable difficulty that the subjects had in achieving muscle deactivation of shoulder muscles. For the shoulder/elbow attempted movement task, stroke survivors had >91% accuracy, and for the paired relax task, brain signal control accuracy was < 51%. For BCI initial session accuracy for the wrist/forearm motor task, imagined, accuracy (training session 1) for the imagined task was > 82%, and was maintained across the subsequent sessions, sessions 2-9, above 80%, with the exception of sessions 6 and 7. For the attempted task, initial session accuracy was >95%, and maintained across the subsequent sessions, sessions 2?, above 80%. For the paired imposed “relax?task, initial session accuracy ranged from 65% to 100%, and was maintained at a range of 70% to 98% across sessions (except for two outliers at sessions 2 and 7).

Discussion and Conclusions

Stroke survivors were able to gain control of brain signal for imposed imagined and attempted shoulder/elbow and wrist/hand tasks. Control of signal deactivation during the relax task was more difficult, across all subjects. And this sample of individuals showed greater difficulty using the shoulder/elbow task versus the wrist/forearm task. Initial session accuracy was sufficiently high to be usable for motor learning for imposed wrist/hand imagined, attempted, and relax tasks.

Q-6 Changes in cortical excitability following the use of a BCI with abstract feedback

Imran Niazi, Ning Jiang, Thomas Lorrain, Alvaro Fuentes cabrera, Natalie Mrachacz-Kersting, Kim Dremstrup, Dario Farina*

BCI technologies can potentially improve the quality of life of people with motor disabilities by providing augmentative communication and transportation systems. Moreover, BCI may have applications in motor rehabilitation, e.g. in stroke patients, by inducing plastic changes in the brain. We hypothesize that training subjects on the use of a BCI based on motor Imagery (MI) would increase the excitability of the cortical areas associated to the muscles that would be active during the task imagined. This hypothesis is based on the psychophysical and physiologic similarities between the actually performed movements and imagined ones and on previous observations that MI can enhance the learning of motor skills. Two healthy subjects (31-33 years) participated in this preliminary investigation. They were trained to two motor imaginary tasks, slow and fast right arm flexion, using an online BCI system that classifies two speeds of imagined movements from features of the movement related cortical potentials (MRCPs). After performance of each imagined task the subjects were presented with abstract feedback (text of different colors) on the result of the online classification. Features from 8 EEG channels were extracted using the discrete wavelet packet transform. These features were classified using support vector machine. The training session for the classifier consisted of 20 trials for each task. The test session was divided into six sub-sessions, each consisting of 10 trials per task. Tasks were presented to the subject in a random order during both the training and test sessions. Each MI test sub-session was preceded by the execution of 10 real tasks to help the subjects maintaining their focus on the MI tasks. The cues for the tasks were presented visually in form of videos of a person performing the movement at the desired speed. This type of visual cues activates the mirror neuron system, which is also activated during actual movements. The changes in cortical excitability were measured from the recruitment curves (RC) elicited by transcranial magnetic stimulation (TMS) applied before and immediately after the test session. The RC was determined from the amplitude of the motor evoked potentials (MEPs) at 100% (L1), 110% (L2), 120% (L3), and 130% (L4) of the resting threshold for each subject. The online classification had average accuracy of 65% and 63% in the two subjects. The RC for the MEPs indicated an increase in MEP amplitude in the two subjects of 9.8% and 103.0%, for intensities close to the threshold level (L1 and L2, respectively), whereas there were negligible changes (1.0 % and 1.1%) for the intensity level of L3, and a decrease of 13.2% and 5.8% at L4. These preliminary results show that cortical excitability may change following the use of an online BCI system with feedback. This result is the basis for the application of BCI to promote cortical plastic changes, which may facilitate the rehabilitation of motor functions. These preliminary results should however be substantiated by a larger subject sample.

Q-7 Correlation between human sensorimotor rhythms and motor cortical excitability during simple hand motor tasks: influence of motor imagery based BCI training.

Floriana Pichiorri*, Annalisa Bononati, Febo Cincotti, Fabio Aloise, Fabio Babiloni, Donatella Mattia

BACKGROUND AND OBJECTIVE

The practice of motor imagery (MI) has been suggested to improve motor recovery after stroke, by inducing plastic changes in the lesioned hemisphere [1]. The Transcranial Magnetic Stimulation (TMS) technique has become a valuable tool to map motor cortex excitability during MI [2]. A modulation of the EEG oscillatory activity within the alpha and beta ranges of frequency (i.e sensorimotor EEG rhythms) occurs during voluntary execution as well as imagination of simple motor tasks[3]. This phenomenon has been exploited to operate some types of EEG-based brain computer interfaces (BCI). In the perspective of developing a BCI-based rehabilitation tool grounded on EEG monitoring of MI, we investigated by means of TMS, if and how the EEG sensorimotor rhythms modulation functionally correlates with the changes in motor cortical excitability during covert hand motor tasks.

METHODS

The scalp EEG and TMS data were collected from 13 healthy volunteers (mean age 25?0 years) who were verbally instructed to either execute (ME) or image (MI) a simple motor task with their non-dominant hand. EEG data were acquired through a 64 channels EEG cap, filtered (band-pass 0.1-70 Hz; sample frequency 200 sample/s) and stored for offline analysis. Single TMS pulses were delivered (at 120% of motor threshold) through a figure-of-eight coil over the right hemisphere in the optimal position to elicit Motor Evoked Potentials (MEPs) in the contralateral Opponens Pollicis (OPP) and Extensor Digitorum Communis (EDC) muscle. EEG epochs (1 sec duration) preceding each TMS shock were analyzed; power spectral density for each channel and each frequency bin (2 Hz resolution) was computed. EEG spectral features and MEP amplitudes were aligned and time series were correlated on a trial by trial basis. The ME and MI tasks were contrasted with baseline condition (Rest).

RESULTS

The performance of ME and MI task induced, in all subject, a significant increase in MEP amplitude recorded from the OPP muscle (ME: $p=.00003$; MI: $p=.05$) concomitantly with a significant EEG desynchronization (frequency range 12-26 Hz; ME: r2 values from 0.15 to 0.5; MI: r2 values from 0.1 to 0.5) localized over the scalp sensorimotor areas. During ME, the increase in MEP amplitude significantly correlated with the decrease in the EEG power spectrum ($p<.01$), in 12 out of 14 subjects. A similar tendency to contra-vary was observed, in all subjects, for the MEP amplitude and EEG features under MI condition; this tendency reached significance ($p<.03$) only in those subject who were previously exposed to a MI-based BCI training.

DISCUSSION AND CONCLUSIONS

The present EEG and TMS findings mainly indicate that MI facilitation effect on motor cortical excitability is variable among subjects, but it becomes very robust in subjects previously trained to perform this cognitive motor task to operate a BCI system. Thus, we suggest that BCI technology and TMS can be successfully adopted to tailor the development of a novel post-stroke “rehabilitation intervention?based on the practice of MI. KEYWORDS: motor imagery, TMS, sensorimotor BCI.

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Q-8 Sensorimotor Rhythm-Based Brain Computer Interface: toward the understanding of training-induced effects on motor cortical excitability

Annalisa Bononati*, Floriana Pichiorri, Febo Cincotti, Andrea Kübler, Christa Neuper, Donatella Mattia

BACKGROUND AND OBJECTIVES

The main purpose of Electroencephalographic (EEG)-based Brain Computer Interface (BCI) technology is to provide for an alternative channel to support communication and control when motor pathways are interrupted [1]. Despite the considerable amount of research focused on the improvement of EEG signal detection and translation into output commands, little is known about how the learning to operate a BCI device would affect brain plasticity which occurs during the learning process. Using Transcranial Magnetic Stimulation (TMS) we investigated if and how a sensorimotor rhythm-based BCI training would induce plastic changes at the motor cortical level. TMS constitutes a non-invasive objective measure of motor cortical excitability modulation occurring under different behavioral settings which involve the motor system [2].

METHODS

Scalp EEG and TMS data were collected from ten healthy volunteers who underwent TMS mapping sessions performed prior and after a motor imagery (MI)-based BCI training, consisting of 6-8 training sessions. EEG data were acquired by means of a 64 channel-cap, filtered (band-pass 0.1-70 Hz; sample frequency 200 sample/s) and stored for offline analysis. Data acquisition, on-line EEG processing and feedback to the subject were performed by using BCI2000 software system [3]. Focal single-pulse TMS was delivered to the scalp using a figure-of-eight coil, placed over the optimal position to elicit Motor Evoked Potentials (MEPs) in the contralateral Opponens Pollicis (OPP) and Extensor Digitorum Communis (EDC) muscles. TMS-derived maps were obtained by stimulating (suprathreshold intensity) multiple scalp sites marked on a 49-point grid mounted on an elastic cap. Volume of the TMS-derived maps (expressed as $\mu V * cm^2$) was obtained by contrasting amplitude of MEPs recorded under MI and rest conditions, before and after BCI training.

RESULTS

All 10 subjects acquired BCI control with accuracy ranges from 53% to 96% in the first training session (R^2 values from 0.04 to 0.6 respectively) and from 81% to 97% in the last session (R^2 from 0.2 to 0.6). The spatial (location) and spectral analysis (frequency) of R^2 values revealed EEG patterns correlating with successful control, localized over the scalp central areas, mainly bilaterally (n=7 subjects), within a range of frequency typical for sensorimotor EEG rhythms (SMR; 12-14 Hz). TMS mapping showed that the EDC and OPP muscle representation estimated before and after training were changed as function of the type of MI tasks that subjects generated to achieve BCI control. A significant increase of the post-training OPP muscle's volume was found in those subjects who adopted a first-person MI of grasping as control strategy (n=5) with respect to subjects performing a first-person MI of fist-clenching (n=5). The EDC muscle representation did not show significant difference between pre- and post- training condition.

DISCUSSION

The main finding of the present study was that motor cortical excitability is dynamically modulated following MI-based BCI training. Since MI appears to be a promising intervention in motor rehabilitation after stroke [4], our finding corroborates the recent idea of exploiting BCI technology to restore motor function by "guiding?activity-dependent brain plasticity to improve post-stroke rehabilitation outcome.

Keywords

BCI, TMS, Motor Imagery

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Q-9 Approaching rehabilitation of severe Acquired Brain Injuries through a neurophysiological screening

Monica Risetti*, Angela Riccio, Febo Cincotti, Rita Formisano, Donatella Mattia

Background

Severe Acquired Brain Injury (ABI) may evolve in disorders of consciousness (DOC; Schnakers C. et al, 2009) like Vegetative State (VS) and Minimally Conscious State characterized by a lack-of or minimal responsiveness, and/or in a Locked-In Syndrome (LIS) in which communication is prevented. A systematic neurophysiological screening, based on parameters like Event-Related Potentials (ERPs) and EEG background activity, can be a first step to follow-up the clinical evolution of ABI patients during their rehabilitation phase. The relevance of such neurophysiological parameter monitoring is evident when considering the potential role of BCI technology in augmenting or even allowing communication, during the rehabilitation of these patients.

Methods

An auditory oddball paradigm (Sutton et al., 1965), previously validated in healthy subjects, including duration, deviants and subject own name (SON; Laureys et al., 2004) presented as a novel, was applied in 7 patients recently diagnosed as VS (n=2), MCS (n=4) and LIS (n=1), mainly by means of the JFK Coma Recovery Scale-Revised, and recruited during their rehabilitation period. Patients were presented with 6 blocks of 500 stimuli (delivered through a BCI2000 Software; Schalk et al., 2004) while the scalp EEG was recorded and monitored continuously throughout each recording sessions. These latter were repeated at least twice following patient’s clinical evolution and outcome during rehabilitation.

Results

Among recruited patients, in 3 of them (1 VS, 1 MCS and 1 LIS) we found a P3 component with latency and amplitude ranging from 208 to 397 ms and from 3,5 to 7,4 μV, respectively. Two patients in MCS displayed only a N2 component; however, in one patient monitoring of EEG background activity revealed a change in the arousal likely due to a sleep state. Finally, one patient in VS and one in MCS did not show clear N2 and P3 components. Only one (VS) of these latter 2 patients, who were recorded after 3 months, showed N2-P3 clear components.

Discussion and Conclusion

These preliminary findings obtained from an initial recruited sample of ABI patients, indicate a certain degree of variability in displaying components of ERPs. Moreover, changes could be detected during rehabilitation phase. This is of relevance to optimize potential rehabilitative intervention exploiting EEG-based BCI technology.

Keywords

BCI; Consciousness; Vegetative State; Minimally Conscious State; Auditory; Oddball paradigm

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R-1 Control of an Artificial Arm with Time Coded Motor Imagery and Error Potential Detection

Alex Kreilinger*, Christa Neuper, Gernot Mueller-Putz

Background and Objective

Current brain-computer interfaces (BCIs) often require long training sessions and, nevertheless, achieve relatively low accuracies. This abstract demonstrates a possibility to deal with the improvement of both of these issues. It was aimed to use a simple mental strategy to control an artificial arm which was decided to be time coded motor imagery (MI) [1, 2] of the right hand. The participants only had to concentrate on one task, however, for varying varying amounts of time. Furthermore, the detection of error potentials (ErrPs) [3] was tested during continuous feedback. Usually, these time- and phase-locked signals can only be triggered by discrete feedbacks. Therefore, a visual discretization of continuous movements was presented to the users.

Methods

Ten subjects without previous experience in MI participated. After one setup run (cued hand MI versus rest, 20 trials each), the best frequency band was chosen, based on ERD/ERS maps (event-related (de)synchronization [4]). By comparing the band-power of MI against rest, a threshold was generated beyond which the hand MI was detected [5]. Afterwards, the actual measurements were conducted. Here, the subjects were presented random target times (1, 2, 3, or 4 s) that told them how long to concentrate on the MI, e.g., 1 s should have resulted in a MI pattern between 1 and 2 s. The time window to perform MI was always 5 s, a progress bar indicated the elapsed time. Afterwards, the artificial arm started to move, depending on how long the MI pattern was detected (between 0 and 5 s). During the artificial arm movement, two different LEDs blinked with 1 Hz, giving information about the future. A white LED predicted at least a whole second of movement to come, whereas a red LED was used to announce a stoppage within less than 1 s. The purpose of this discretization was to allow measurement of ErrPs, triggered by unexpected lights.

Results

Most of the subjects were able to generate significant patterns after only one setup run. During the online experiment, the subjects performed MI exactly as requested (e.g., a target of 1 s calling for MI between 1 and 2 s) in 26 % of the trials, 45 % of the trials were in a range between +/-0.5 s of the target time period, and 68 % between +/-1 s. The discretization resulted in an error rate of 26 % on average over all subjects (unexpected LEDs blinking), which is a good basis to record ErrPs. Concerning the detection of these ErrPs, it could be shown that all of the participants produced waveforms similar to interaction ErrPs [6] recorded over the frontal lobe, however, with a delay of about 200 ms.

Discussion and Conclusions

Very simple mental tasks like hand MI with very little training efforts are sufficient to control neuroprostheses when time coded, even though it is difficult to reach the target time precisely. ErrPs, usually impossible to detect in asynchronous BCIs, could be measured by simply adding discrete feedback to a continuous one.

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Support

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Keywords

brain-computer interface (BCI), error potential (ErrP), electro-encephalogram (EEG), motor imagery (MI)

R-10 Tools for efficiently comparing decoding options for real-time control of upper limb neuroprostheses

Amar Marathe*, Dawn Taylor

Intended arm movements can be decoded from neural or muscle activity and used to control a computer mouse, a prosthetic limb, or even implanted peripheral nerve stimulators that restore movement to one's own paralyzed limb. Although recorded neural signals may be noisy, natural limb movements are generally smooth. Consequently, many algorithms for decoding continuous movement intent from neural signals apply some type of temporal smoothing by using both current and past data (or past predictions) to improve movement prediction at the current time step (e.g. Kalman or linear filters, or decoding strategies that make use of longer windows of data that overlap in time). These smoothing techniques can be very effective in reducing the amplitude of the movement prediction errors offline. However, they also change the frequency content of the errors and, in some cases, add a temporal delay between the actual and predicted movement. Decoding methods that smooth the movement prediction also reduce the responsiveness of the decoded movement commands, which hinders one's ability to make corrective movements online. Furthermore, if the device being controlled has mass and inertia, such as a prosthetic limb, the device itself also acts like a low-pass filter causing additional reductions in responsiveness. While smoothing techniques significantly improve offline decoding accuracy, it is unclear if the pros of better decoding outweigh the cons of reduced responsiveness for any given decoding option. In this study, we characterized the effect of various temporal smoothing methods on real time control. Able bodied individuals performed a target matching task in virtual reality where the movement of a cursor was controlled by the actual position of their arm. Artificial noise with various amplitudes and frequency distributions, along with temporal delays, were systematically added to the virtual arm movements in real time to simulate the prediction error and delay characteristics of a wide range of common decoding methods . The subjects?performances during this target matching task were used to build a general model to describe the effect that the magnitude and frequency content of the prediction error, and delay in prediction have on online performance. This model would enable researchers to efficiently estimate and compare online movement control performance of many different decoding options without having to do online testing of each option individually. To validate the model, arm movements were predicted in real time from intracortical activity (monkeys) and proximal arm EMGs (humans) using different decoding methods that employed a variety of temporal smoothing techniques. Subjects used the intracortical/EMG-predicted arm movement to control the movement of a cursor in a target matching task. The subject's actual online performance was compared to the model predictions to determine if the model could identify which decoding option would work best for online control. Our results indicate that this model can be a valuable tool to identify decoding methods that perform well in real-time control environments based solely on characteristics of the offline data set.

R-11 Towards Hierarchical BCIs: Combining Motor Imagery and Evoked Potentials for Robotic Control

Mike Chung*, Reinhold Scherer, Rawichote Chalodhorn, Rajesh Rao

BACKGROUND AND OBJECTIVE

Evoked potentials provide a relatively accurate way of selecting between a large number of classes in EEG-based BCI systems. However, due to their reliance on external stimuli, they are unsuitable for fine-grained control. Motor imagery, on the other hand, does not require external stimulation and allows real-time control but can be error-prone. We propose a new approach to building scalable, user-adaptive BCIs that combines the advantages of motor imagery and evoked potentials. Users utilize motor imagery to teach the BCI new commands, which are then made available for selection using evoked potentials (e.g., the P300). This leads to a hierarchical BCI system wherein lower-level actions are first learned and later semi-autonomously executed using a higher-level command, freeing the user from having to engage in tedious moment-by-moment control. We explore the efficacy of such a system in the context of a hierarchical BCI system for controlling a humanoid helper robot. To investigate the feasibility of such an approach, we performed a first set of EEG-based BCI experiments that intermixed motor imagery and P300 control tasks.

METHODS

EEG signals over sensorimotor and visual areas were recorded from 4 able-bodied volunteers while performing cue-guided motor imagery (MI, 2-classes) and focused attention P300 (2/4-classes, 8 flashes per class) tasks. Images used to evoke the P300 were arranged on the screen in a 2x2 grid and highlighted for 125 ms every 250 ms. Four runs, each with 20 imagery trials and 12 P300 trials (4 per class) intermixed with each other, were recorded. For the imagery task, classes were discriminated using common spatial patterns (8-30 Hz, 1 projection) and Fisher's linear discriminant analysis. For the P300 task, 1-second EEG segments (0.5-8 Hz) following each flash were spatially projected (3 filters) and classified by a support vector machine (SVM); the image with the highest number of hits was selected. The methods were trained with the data of runs 1 & 2 (for simplicity, parameters such as the SVM regularization parameter were not tuned for subjects and were based on prior experiments). The methods were evaluated on data from runs 3 & 4.

RESULTS

We obtained the following average accuracies (standard deviations) over four subjects for 2-class imagery, 2-class P300 and 4-class P300-based selection: 76(8)%, 96(5)% and 84(5)%. For comparison, the corresponding 2- and 4-class chance levels are 50% and 25%, respectively.

DISCUSSION AND CONCLUSIONS

The preliminary results from our offline study suggest that users can switch between the modalities of motor imagery and evoked potentials, and achieve reasonably high accuracies in each case. These results constitute a first step towards building a hierarchical BCI system based on combining imagery and P300 for controlling a robot. The specific robot we intend to use is a Fujitsu HOAP humanoid robot which is equipped with vision and other sensors, and possesses the ability to walk, side-step, pick-up and drop off objects. Our next series of experiments will investigate whether users can maneuver the robot using imagery and later invoke these user-taught behaviors directly through P300-based commands.

Support

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Keywords

Hierarchical BCI, Electroencephalogram (EEG), imagery, P300, humanoid robot

R-12 Network Dynamics and Neurally Enabled Autonomous Robots

Cali Fidopiastis*, Chris Berka, Sharon Shaw

Background and Objective:

The motor cortex continues to play a dominant role in brain- computer interface (BCI) research and applications. While the motor cortex displays many of the characteristics needed to successfully employ brain activations as input to a device (e.g., reliable, repeatable brain signatures), there is a need within military applications to better understand potential brain inputs generated outside this area, especially when considering neurally enabled autonomous robots. Human-robotic interaction currently entails the Warfighter to remotely monitor and command their robot team members through interfaces that place high cognitive demand on the human operator. This high cognitive load is typically due to communication delays caused by the distance between the Warfighter and the robot. Monitoring robot status while remembering commands sent through a typical graphical user interface using a keyboard and mouse within a battle station may be compromised further by the stress of combat. Brain-computer interfaces may provide a solution to the human-robot dilemma by providing a means to translate intention of the operator into robotic action. However, the current means of implementing brain-computer interfaces may not be conducive to this endeavor. For example, training the system can take hours; as well, the neural commands may be limited in number due to the signatures obtainable from the motor cortex.

Methods

Non-invasive BCI typically entails user control over mu (8-12 Hz) or beta (18-26 Hz) rhythm amplitude using either real movements or motor imagery. The brain signals generated from the motor cortex are easier to isolate and extract than training tasks requiring more complicated brain interaction. We review the latest research in dynamic and functional mapping of cognitive states and relate them back to the question of how to create BCI capabilities that work for military applications such as operating autonomous robots used in the theatre of war.

Results

A literature review of the BCI field suggests that many applications continue to tap the motor cortex as a means to extract reliable EEG signatures to drive communication between humans and machines. However, there is also new research in the field of neural dynamics that suggests that reliable signatures outside the motor cortex are attainable.

Discussion and Conclusions

In this theoretical work, we discuss the need for moving beyond the motor cortex to extracting signals from the brain network. We provide a review of current work in the neurally enable robotic field and discuss implications for the traditional use of brain-computer interfaces as a prosthetic device for persons with disabilities. Keywords: autonomous agents, human robot interaction, neurally enabled, dynamical neuronal systems

R-2 Towards natural arm control: classification of hand and elbow movements

Gernot Mueller-Putz*, Vera Kaiser, Alex Kreilinger, Christa Neuper

BACKGROUND & OBJECTIVES

A major problem in high spinal cord injured patients (lesion above C4) is that they lose control over their grasp and elbow functions. With the help of neuroprosthetic systems, it is possible to restore simple hand and arm movements. It seems that for those cases, a non-invasive Brain-Computer Interface (BCI) based on EEG signals provides a good option to control such devices. After first attempts at using a BCI for hand control are already made [1, 2], the aim of the following study is to investigate whether the imagination of hand and elbow movements can be used for neuroprosthetic control. To start with, here we describe a first investigation of the separability of executed as well as imagined hand and elbow movements.

METHODS

Fifteen healthy subjects participated in this study. EEG was derived monopolarly from 32 electrode positions covering sensorimotor areas. The experiment was twofold: (i) first, they were asked to follow a cue-guided paradigm and therefore executing brisk hand and elbow movements randomly (40 trials each). (ii) Second, subjects were asked to imagine the same hand and elbow movements according to the paradigm (120 trials each). By applying a common spatial pattern (CSP) analysis [3] and 10x10 fold cross validation we calculated the classification accuracy for both, data from execution and imagination. Furthermore, for a more physiological overview event-related (de)synchronization (ERD/S) maps were calculated [4, 5].

RESULTS

Classification accuracy of 14 subjects (one data set was rejected) is presented: (i) motor execution ?here, the mean classification was 78.1 % (SD 8.2). (ii) motor imagery ?classification accuracy was 64.0 % (SD 5.5). Applying a t-test showed that the results from motor execution were significantly higher than those from motor imagery. Though motor imagery classification accuracy is rather low, it is significantly higher than random (see [6]). ERD/S maps show a clear difference between hand and elbow movement, especially at electrode position C3 and C1b.

DISCUSSION & CONCLUSION

In this study we investigated whether it is possible to separate hand and elbow movements (real executed as well as imagined) by analyzing EEG signals from corresponding brain areas. We have shown that it is possible to reach a separability of about 78 % in 14 naive subjects after execution and 64 % after imagery. The next step is to analyze data from imagined hand and elbow movements and refine signal analysis for the realization of a control for a hand/arm neuroprosthetic device.

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Support

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Keywords

Brain-Computer Interface (BCI), Electroencephalogram (EEG), Neuroprosthesis

R-3 Number of command sources required for a set of functional upper extremity endpoint postures

Brian Murphy*, Robert Kirsch

Background and Objective

High level tetraplegia (C1-C4) results in paralysis for many mechanical degrees of freedom (DOF) and leaves a small number of possible command sources to control movements restored by functional electrical stimulation (FES). Existing command interfaces (e.g. EEG, facial EMG, sip-and-puff) currently provide a smaller number of independent commands than the number of joints in the arm. Thus, an effective way for the user to control coordinated movements of the whole arm using a low-dimension of commands needs to be established. Earlier work using dimensionality reduction techniques has demonstrated kinematic synergies between joints of the upper extremity during reaching movements, suggesting that the underlying command dimensionality is less than the number of joints. These studies examined the movements of able-bodied subjects, however, which may not be the most effective way to find the minimum number of commands necessary for control for a paralyzed individual with an FES system. Thus, the goal of this project is to find the minimum number of independent commands needed to achieve adequate performance in controlling a set of multi-joint arm movements relevant to the functional needs of an individual with high level tetraplegia. Method We used a kinematic model of the human arm and an optimization technique to find the mapping between a number ($N < K$) of independent commands and a larger number ($K = 7$) of arm joint angles. Specifically, a set of functionally relevant postures and the number of commands are first specified, and the optimization procedure then minimizes the error between the simulated task postures and the desired task postures. The optimization program finds the matrix mapping input commands to joint angles simultaneously with the command values to minimize both the 3D Cartesian and 3D orientation kinematic endpoint errors. We are investigating the increase in performance as a function of number of commands.

Results

Endpoint postures were chosen to span the workspace as well as be representative of functional tasks. Preliminary results for a limited number (~20) postures indicate that increasing the number of commands from 2 to 3 resulted in a large decrease in error. Further increases in the number of commands results in even lower error, although the additional improvements are smaller. Certain positions also appear to be more difficult for the optimization to reach than others. Ongoing work will examine a larger number of postures.

Discussion and Conclusions

We have developed a model-based technique to explore the relationship between number of available commands and the ability to specify a number of functionally relevant arm postures. The results of this study will influence our efforts to develop BCI and other user interfaces to control FES arm systems, in particular estimating the minimum number of independent commands needed to implement a functionally effective system. Assuming that a user can generate the optimal commands (with practice), the map between command inputs and joint angles could be used in future FES systems. This approach can be customized to evaluate different arm postures of interest and for different arm dimensions.

Support

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Keywords

Optimization, FES, BCI, Synergies

R-4 Title: Development of framework to quantify benefit of diverse command signals in a Brain Computer Interface: a data fusion simulation

James Liao*, Robert Kirsch

Background and Objective

Brain computer interfaces (BCIs) may provide effective user interfaces for systems that restore function to individuals with severe paralysis due to Spinal Cord Injury (SCI), Stroke, ALS, or limb amputations. Decoded efferent neural signals can control a functional motor or communication prosthesis. However, performance is limited by the number of independent degrees of freedom (DOF) that can be decoded, the accuracy and precision of the decoded signal, and the responsiveness of the decoding algorithm. Traditional BCIs for upper-extremity prostheses have focused on signals derived from motor or premotor cortex, representing movement kinematics such as position or velocity. Recent literature demonstrates that qualitatively different signals representing movement goals or timing can be decoded from other brain areas. Our hypothesis is that utilizing qualitatively diverse signals from multiple brain areas will improve the performance of a BCI for controlling an upper extremity neuroprosthesis. As an initial step, we performed the analysis using simulated signals.

Methods

The simulation assumes the availability to decoded signals related to movement kinematics (position and velocity), as well as goal position and time-to-goal (e.g., from motor and parietal cortex). A sequence of random points in the workspace represents a set of reach goals. A minimum-jerk algorithm generates 3D trajectories between each reach goal. From these trajectories, signals are derived that correspond to movement kinematics, goal position, and time-to-goal. These signals represent simulated decoder output from the aforementioned brain areas. The signals are fused via an Artificial Neural Network (ANN) whose output is a single command signal to the prosthesis. Feedback was included via a statistical model (Fishbach et al, in Exp Brain Res 177:45-63, 2007) that allows the trajectory planner to generate appropriately timed corrective reaches if predicted endpoint error exceeds a threshold.

Results

With trajectories corresponding to 100 reach goals per training set and 10 goals per validation set, and an inter-goal interval of ~5 seconds, one experimental run takes several hours on current PCs. In the validation set, we used goal-centric performance measures including throughput (reference matt's paper or thesis?) and a backwards stepwise elimination algorithm to determine relative importance of each signal.

Discussion and Conclusions

We have built a system that can predict the relative contribution of each signal and brain location to overall performance. This approach relies on literature that demonstrates presence of certain types of information in certain brain areas. The next step is to run multiple permutations of signals and noise amplitudes. Several research paths may lead to increased BCI performance. We have assumed that the decoder is ideal in that residual errors or noise is random. Given ideal decoders, do current implant locations contain enough information to perform reaching tasks realistically in a BCI? Which brain locations are most important? What is the range of decoder noise that can be tolerated? We believe that our simulations will help to answer these questions. This effort will help direct future BCI research and suggest brain locations for implant.

R-5 Improving Invasive and Non-Invasive BCIs for General and Neuroprosthetic Applications

Dawn Taylor*, Dan Bloomberg, Holle Carey, Stephen Foldes, Longlong Cheng, Harrison Kalodimos, Amar Marathe, Abirami Muralidharan, Kathy Ward

BACKGROUND

Our lab is evaluating invasive and non-invasive recording options primarily for applications in upper-limb neuroprosthetic control. We are addressing several problems that are common to all applications, and also trying to maximize online movement control specifically for upper limb neuroprosthetic applications.

METHODS/RESULTS

Broadly-applicable lab projects: - Determining ways to speed up the recursive feature selection process without compromising decoding accuracy: Accurate recursive feature selection (with cross validation) is important for identifying which signals/features to include/exclude in decoding. However, this process can take hours or even days when evaluating large numbers of signal and features. Quicker methods are needed in order to use feature selection to optimize decoder performance within a patient testing session. Methods to speed feature selection include identifying if some features should be kept/discarded outside of the recursive testing loop, optimizing ratios of testing/training data, simultaneous optimization of multiple dimensions, etc.. Results indicate that good rapid feature selection can be done within a patient testing session, but strategies should be customized for different types of data. - Determining how different signal processing and decoding function properties impact the user's ability to correct for movement errors online: Methods include imposing known delays, velocity gains, and movement error characteristics on individuals?actual arm movements in a virtual target acquisition task to see how these factors effect online movement error correction. Results indicate that decoding functions with primarily low frequency components in their prediction error can confound a person's ability to correct for these errors in online control tasks. Neuroprosthetic-specific lab projects: - Determining the feasibility of EEG-triggered stroke therapy. For people with complete hand paralysis post stroke, EEG-triggered assisted-movement therapy may improve reorganization and recovery by re-establishing a tight causal relationship between brain activity and peripheral sensorimotor activation. Methods include optimizing decoding parameters to very rapidly detect the intent to extend the fingers from EEGs in moderate and severe stroke patient. The goal is to detect intent to move prior to any actual movement onset. Results indicate that rapid detection is possible in both moderate and severely paralyzed stroke patients. - Field potential-control of an upper-limb neuroprosthesis. We have shown that a virtual upper-limb neuroprosthesis can be controlled in 2D with EEGs by attempting to move/rest two different unrelated body parts (e.g. hands and feet). We are working to provide more natural EEG and ECoG control of a neuroprosthesis by decoding movements of individual joint of the arm/hand. Methods include optimizing spatial filters and classifier functions to detect the relaxed/extended state of different arm joints and applying classifier outputs to incrementally flex/extend those specific joints in a virtual neuroprosthesis. Preliminary results suggest signals related to neighboring arm joints can be separated and used independently for arm joint control

CONCLUSIONS

These and several other projects in our lab are moving the BCI field forward by make movement decoding more efficient and appropriate for real-time applications such as neuroprostheses.

Support

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R-6 Asynchronous Brain Computer Interface Control of a Walking Simulator

An Do*, Po Wang, Christine King, Luis Chui, Zoran Nenadic

Background and Objective

Individuals with paraplegia due to spinal cord injury (SCI) are unable to ambulate. Current systems using functional electrical stimulation (FES) provide an alternative method for standing support and ambulation, but their operation requires a manual control box, which is unintuitive. Electroencephalogram (EEG) driven brain-computer interfaces (BCIs) can potentially integrate with FES technology to restore brain-driven, intuitive ambulation to these patients. Here, we describe the design and successful implementation of an “intuitively?operated BCI-controlled walking simulator.

Methods

Subjects and Training Data Acquisition: EEG signals from three healthy subjects were acquired using a 32-channel EEG cap and amplifier (Nexus 32, Mind Media, The Netherlands) using 10-20 International Standard and common average referencing. Training data was collected while subjects performed motor imagery (MI) as they watched a video of a 3D avatar alternating between five minutes of standing and walking. Signal Processing and Classification: EEG signals were divided into 4-sec segments, resulting in 75 samples for each mental state. Spectral energies in 6 ?26 Hz band were calculated using Fourier transform. Classwise principal component analysis and linear discriminant analysis reduced the input dimensions to 1D feature space. Linear Bayesian classifier was used to classify the mental state. Evaluation of BCI Control: Subjects were seated in front of a computer screen, while EEG data were acquired and classified. A 3D avatar in an open field virtual environment (VE), using Garry's Mod for Half Life 2 (Havok Engine, Valve Corporation, Bellevue, Washington), was displayed from a third-person, "over-the-shoulder?perspective. Subjects were instructed to use walking MI to move his/her avatar to greet a series of 10 "non-player character (NPC)?positioned along a linear path in front of the subject's avatar, similar to Leeb et al [1]. Subjects must stop within a proximity of the NPC and stand still long enough to receive a verbal greeting. After this greeting, subjects were to initiate walking towards the next NPC until all 10 were greeted.

Results

All subjects obtained meaningful control immediately. Subject 1 averaged 6.8?.8 NPC greetings per trial. Subjects 2 averaged 8.0?.0 NPC greetings per trial. Subject 3 averaged 7.0?.16 NPC greetings per trial. When compared to simulated random walk (2.7?.3 NPCs), these subjects demonstrated purposeful control ($p < 0.0001$).

Discussion and Conclusions

An asynchronous BCI was successfully implemented to control ambulation in a VE. Linear ambulation in a VE is the closest scenario to actual use of a potential BCI-controlled FES device, demonstrating that such a concept may be imminently feasible. In addition, employing automated signal analysis techniques described in [2], allowed for setup without manual selection of EEG channels or signal features, and subjects could utilize a "natural?MI, i.e. walking MI to walk in the VE. Together, these allowed users to gain immediate control, which may have implications in practical clinical BCI applications. Further studies are necessary to implement other degrees of freedom of control, such as turning left and right, and to determine if this technique can be extended to individuals with paraplegia due to SCI.

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R-7 Controlling Wheelchair Tilt with a Brain-Computer Interface

David Thompson*, Michael McCann, Jane Huggins

Background and Objective

While wheelchairs have been controlled by a brain-computer interface (BCI) (e.g. [1,2]), systems that allow the operation of a subject's own wheelchair are not available. Although the technology to build such systems exists, the speed and reliability of most BCIs brings up important safety concerns for use outside a laboratory environment. Control of a wheelchair-mounted tilt-in-space seating system, however, can provide important benefits to people with amyotrophic lateral sclerosis (ALS), while avoiding many of the safety concerns associated with driving a wheelchair. Since ALS does not affect the sensory system, individuals with ALS can feel discomfort from sitting too long in one position, but may be physically unable to address the problem. The variety of wheelchairs and the proprietary nature of their interfaces are obstacles to building a system that can control multiple wheelchairs. Additionally, safe control of tilt requires feedback, which is not provided by the chair. This work presents a system for control of wheelchair tilt based on a P300 interface provided by BCI2000 [3], our Multi-Purpose BCI Output Device (MBOD) [4], and a MotionNode Accel [5].

Methods

The MBOD can produce switch closures to interface BCI2000 and the wheelchair. Wheelchair systems usually have accessories available for controlling the chair using physical switches, often through a reversing relay. These accessories may have to be purchased or the chair electronics programmed. However, the use of switch outputs from the BCI allows for a nearly universal control system that is expected to work even for future wheelchair seating systems. A feedback loop was used to control the tilt angle and ensure the desired function from the reversing relay. Feed-forward systems are inherently unstable and therefore unsuitable for home use, where people or obstacles might interfere with tilting movement. We used a MotionNode Accel, a 3-D USB accelerometer mounted to the chair, to measure the current tilt angle. This also allows artificial movement limits for added safety (people with ALS may have difficulty breathing in a full reclined position). Finally, BCI2000 was configured to allow chair control. We explored preset positions, small relative movements, and continuous control.

Results

We have successfully used the system to control the tilt of our laboratory wheelchair, using both preset positions and relative movements. Continuous control is not practical because the chair can move through its entire range of motion in 18s. Even the fastest P300 typists would only have two or three stopping positions in that time, assuming the movement started from one of the rails. We are procuring equipment to connect a second wheelchair to the system.

Discussion and Conclusions

The results from the work were encouraging, and the system will soon be used for both our first in-home subject with ALS and for experiments on the effects of movement on BCI usage. While wheelchair interfaces are proprietary and non-standardized, switch interfaces are available for many or all wheelchairs (though there is the issue of price). This system should work well for a variety of chairs, but further testing is required.

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Support

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Keywords

BCI, wheelchair, tilt, MBOD

R-8 Chronic hand paralysis after traumatic brain injury: a case report on the use of a brain-computer interface to operate a mechanical hand orthosis

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Background/ Objective

An estimated 80,000 civilians are left with long term disabilities from traumatic brain injury (TBI) annually in the United States alone[1]. Chronic severe motor impairments caused by neurological damage may respond poorly to current rehabilitative interventions. Brain-computer interface (BCI) systems may have a role in neurorehabilitation. The objective of this proof-of-principle case study was to determine whether a TBI patient with chronic hand paralysis could learn to use a BCI to move a hand orthosis by imagining the paralyzed hand opening and closing.

Methods

The patient is a 39 year old woman who suffered a moderate TBI (Glascow Coma Scale = 7) in a motor vehicle accident in 2002, with subcortical damage of the corticospinal tract. The patient has residual paralysis of the left hand. Brain activity was recorded with a 275 channel magnetoencephalographic device (CTF Systems, Inc., Canada). BCI2000 software was used to analyze changes in mu rhythm activity (11Hz) during performance of two tasks, imagined hand movement and rest (controlled breathing), and drive the hand orthosis in real-time. The analysis was based on 3 sensors that had shown a high correlation between the tasks in a series of feature extraction sessions, and were positioned over the lesioned (right) hemisphere for the purpose of facilitating plastic changes in ipsilesional motor regions. The patient participated over the course of 2 months in 12 training sessions with the contingent feedback. Retention was tested 3 months later. The task during training and retention was to use the BCI to move the orthosis attached to the paralyzed hand as much as possible. The orthosis provided continuous online feedback of success by mechanically opening and closing the hand. Thus the task required learning to maintain or increase mu desynchrony for as long as possible in each trial as a decrease would cause the orthosis to stop moving. The percentage of time the orthosis moved per trial was taken as a measure of performance.

Results

Paired t-tests indicated performance in session 12 was significantly better than in session 1 ($p=.002$). In session 1 the orthosis moved for an average of 54% of the time while in session 12 it moved 64% of the time. There was a positive correlation between performance improvement and sessions ($r=0.64$, $R2=.40$). This improvement was lost when the patient was retested after 3 months; session 13 (55%) did not differ from session 1 ($p=.92$). Clinical assessments of motor function failed to indicate functional gains at the end of training.

Discussion/ Conclusions

The data indicate a gradual but consistent improvement during training in the ability of the patient to move the hand orthosis. These findings demonstrate that a person with moderate TBI can use motor imagery to operate a non-invasive BCI driven by sensors over the lesioned hemisphere to operate a mechanical hand orthosis. The lack of a retention effect in this patient, however, indicates that regular practice with the BCI may be necessary. Additionally, she may benefit from an implanted or portable BCI that accommodates for corticospinal tract damage. Reference: Centers for Disease Control and Prevention. Facts about traumatic brain injury. 2006

Support

Intramural Research Program of the NIH, NINDS, and the Deutsche Forschungsgemeinschaft (DFG)

Keywords

Brain-computer interface; MEG; traumatic brain injury

R-9 The P300 Brain Computer Interface as a controller of a wheelchair mounted robotic arm system

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The P300-BCI was originally designed to allow individuals who are in a locked-in state to choose letters from a screen to spell out words. More recently, there are attempts to adapt BCIs to control assistive devices such as wheelchairs, robotic arms, and even implantable neuroprostheses. We report an experiment in which we demonstrate that the P300-BCI can be used to communicate a selected character from a 5x3 matrix to the controller of a wheelchair-mounted robotic arm (WMRA). To control the WMRA via the BCI the user is presented with a visual matrix whose rows and columns intensify randomly. Each of the characters in the matrix corresponds to a specific direction or task command. The chosen character from the BCI is sent to the WMRA control program, which translates it into a Cartesian velocity in the proper direction and executes the algorithm to move the arm. To test the application of the P300 BCI as a controller of the WMRA, speed and accuracy data were collected while six healthy young adults from the University of South Florida chose specific characters from the 5x3 BCI display to achieve specific movements by the robotic arm. Accuracy level was measured by comparing the character to be selected with that chosen by the BCI system after it examines the recorded data in real time. We report accuracy levels of character selection as a function number of sequences of intensifications of rows and columns. We will discuss our current challenges in developing a system that is able to dynamically estimate and represent the user's intentions in relations to the changing environment, to communicate these intentions in the most efficient manner to the robotic arm which has the intelligence to perform the task effectively and safely.

S-1 Solved and unsolved issues in BCI-applications

Niels Birbaumer*

We provide an overview of recent advances in clinical applications of the BCI technology and its potential for technological multiplication. BCIs using Electroencephalographic recordings were shown to allow verbal brain communication in amyotrophic lateral sclerosis (ALS), also in the locked-in state. Completely locked-in patients could not communicate even after neurosurgical implantation of electrodes in the brain. Reasons for this situation and solutions are presented. BCI for brain communication is now ready for multiplication. In motor restoration in chronic stroke and spinal cord paralysis only one controlled study of the author's group is available (Buch et al 2008 in Stroke) demonstrating complete control of hand opening and closing in chronic stroke with a magnetoencephalographic BCI but no generalization outside the laboratory. Preliminary results of a new controlled study on chronic stroke using EEG and implanted electrodes will be presented. Behavioral psychiatric disorders usually are caused by subcortical brain dysfunctions. A new BCI for subcortical brain areas using functional magnetic resonance imaging (fMRI-BCI) and near infrared spectroscopy (NIRS) was developed and tested in attention deficit disorders, criminal psychopaths and schizophrenia, in addition to memory disorders and addiction.

Results are highly encouraging and would allow technological application at a large scale using NIRS.

S-2 Future Directions in Brain/Neuronal Computer Interaction

Brendan Allison*, Jose del R. Millan, Anton Nijholt, Stephen Dunne, Robert Leeb, Mannes Poel, Diane Whitmer, Christa Neuper

Brain-Computer Interface (BCI) research has made great progress recently [1-3]. However, this progress has some negative side effects: growing fragmentation among different researchers, confusion about the best research directions, and ongoing disagreement over terms and definitions. Future BNCI is a Coordination and Support Action funded by the European Commission that aims to counteract these trends by helping new and existing researchers identify each other, encouraging effective collaborations, developing roadmaps and frameworks, and establishing standardized terminology. The knowledge developed in Future BNCI will be disseminated through conferences, workshops, journal publications, a book, and a website. This website (future-bnci.org) is meant as a centralized resource to benefit our BCI community. The website will include many resources that should be useful to the BCI community, including databases of peer-reviewed references , articles in the popular media, researchers and research groups, conferences and other events, and downloadable materials. We will also have a blog, some BCI success stories, and a Wiki. The website will be tailored to meet the needs of different groups, including professional researchers, journalists, students, patients and other potential users, and the public at large. We emphasize that we view this website as a community resource, and rely on you ?the BCI community ?to help keep it updated and complete. The website is designed to allow people to add new information, pending approval by our consortium, and we encourage you to go to our web page to add (at least) your research group and interests. We also hope to attain some of our other goals through discussion with the BCI community. We welcome your views on (for example) which applications are most promising, how BCIs can best be combined with other interfaces and systems, or which user groups are likely future adopters. Workshops at this International BCI conference and other conferences can facilitate this discourse, and we also welcome your views via our website, other discussions, email, and other mechanisms. We recognize that BCI research is an eclectic field, and we'd like to hear from people from different disciplines (such as neuroscience, psychology, HCI, programming, and different fields of engineering) and different sectors (such as academic, medical, commercial, and nonprofit). Our consortium includes four institutions: TU-Graz, EPFL, University of Twente, and Starlab. The first two institutions are well known for their BCI research, with emphases on signal processing and applications. TU-Graz is responsible for Project Coordination and "Roadmaps and Dissemination? while EPFL is responsible for "Devices, Applications, and Users? University of Twente is atop HCI research institution, and manages the front end of our web page as well as "Application Interfaces and Environments? Starlab is a prominent manufacturer of sensor systems that can detect EEG and other physiological signals, and will manage "Sensors, Signals, and Signal Processing? This International BCI Conference is an excellent venue to discuss our project and its goals with key stakeholders in our research community. We look forward to hearing your views and working toward our goal of a more integrated, effective, focused, and productive research community.

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Keywords

BCI, BNCI, future BNCI, roadmaps, standards, frameworks

S-3 Soft Targets: Brains and BCIs as Security Liabilities

Matthew Wilczynski*, Brendan Allison

BCIs have developed substantially since Gray Walter debuted his brain-controlled slide projector in 1964 [1-3]. Current applications of BCI systems range from controlling commonly used computer programs to operating household appliances and surfing the internet, and the combined methods of capturing and translating neural signals for these applications are as also quite varied. Many new user groups are emerging as well, including healthy users who may use BCIs for various reasons, such as hands-free control or (presumably) secure communication [4]. However, BCI designers rarely discuss the security implications of the systems they create. As BCIs move further away from research laboratories, and hence further away from experts who must follow confidentiality guidelines, the need for "hardening" diverse BCI systems in real-world settings increases. Ironically, nearly all of the attention to BCI security issues stems from science fiction. Many “bci fi?works present nightmare scenarios of compromised BCI systems, including the recent movie ?Surrogates,?as well as Strange Days, Dreamscape, The Lawnmower man, different incarnations of Star Trek, X-Men, and the Matrix, and books like “Neuromancer?and “Feed.?We are very far away from most of these scenarios, which typically assume that BCIs can write to the brain or have other capabilities well beyond modern technology. Realistic concerns involving BCI security in the near future instead arise from vulnerabilities that lie both in the BCI-specific machinery as well as the pastiche of more familiar systems which comprise a complete BCI system. An example of a BCI specific concern is unwanted EEG data mining. A user may intend to use his EEG activity only to play a game, but unprotected raw EEG data could also be used to identify a psychological disorder, find out whether someone was interested in offensive or politically sensitive material they viewed, or assess use of alcohol, medication, or illegal drugs. Other concerns (and potential countermeasures) are not specific to BCIs. For example, hackers might determine which messages or commands a user sent, including a credit card number or user authentication signal [4, 5]. These concerns may be relatively minor when a patient uses a P300 to spell words on a monitor, and only family members and a PhD student ever access the raw and processed data. However, the risks increase considerably when BCIs are incorporated into mainstream home systems like browsers, networked utilities, and even full-featured text editors. Hackers will likely not distinguish between valuable personal data stored in a conventional system and that of a BCI. A world of increasingly ubiquitous BCIs requires new types of endpoint and input security that are not normally considered in other domains. We highlight some key problems in treating BCIs as purely developmental or experimental devices and neglecting the devastating possibilities of compromised systems “in the wild? We discuss the most likely failure scenarios and opportunities to prevent or respond to concerns. These include both novel BCI-specific operating system security features and adaptations of existing security measures.

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T-1 Preferred programming languages to illicit steady state visual evoked potentials from a CRT monitor

Dwight Waddell*, Aik Min Choong , Joseph Smith, Fei Teng, Christopher Reichley, Pamela Lawhead, Yixin Chen

Background and Objective

The steady state visual evoked potential (SSVEP) is currently used as a means by which patients with locked-in syndrome or other forms of paralysis are able to interface with a computer thereby communicating with the outside world. Specifically, the SSVEP is a physiological potential measured from the occipital cortex that entrains to the frequency of a stimulating signal. A practical use for SSVEP is matching the entrained frequency to a spatial location representing a series of alpha-numeric characters thereby allowing a user to "type" by visually fixating on the desired character. Much of the current research involves increasing the speed by which character recognition can be achieved. Jaganathan et al. argue that the computer architecture and operating system impose a known variability between the desired stimulating frequency and the actual stimulus produced by the screen. We hypothesis that the programming language used to generate the stimuli will also impose additional variability within the signal. The purpose of this study is to validate our hypothesis and determine which programming language minimizes artifacts between the program-generated stimulus and the signal displayed on the computer screen (CRT).

Methods

A 300 by 300 blinking pixel box (stimulus) was presented on a CRT monitor with a resolution of 1280 by 1024 pixels at a 75 Hz refresh rate. A Digital Instruments LX-102 light meter was placed directly against the monitor to measure the blink rate of the stimulus. The signal obtained from the light meter was then supplied to an Agilent 54621D Mixed Signal Oscilloscope and subsequently input back into the computer through the "line in" channel. A Fast Fourier Transform (FFT) was performed on the digitized "line in" data to obtain a plot of the frequencies present. The programming languages tested in this study included: Java, Java with OpenGL, MATLAB, C++ with DirectX, C#, C# with DirectX, and FlashMX.

Results

The results of this study indicate that C++ with DirectX provided the most precise and accurate representation of the stimulus. The other languages imposed a frequency shift between the stimulating frequency and that observed on the monitor, and a reduced signal to noise ratio.

Discussion and Conclusions

C++ with DirectX is likely the best platform because of its lack of language overhead allowing the programmer more direct access to the core processor.

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Keywords

SSVEP, Programming Languages, CRT

T-2 Harmonics in SSVEP: Are They Evoked by the Fundamental Frequency or by the Artifacts of the Stimuli?

Fei Teng*, Aik Min Choong , Scott Gustafson, Dwight Waddell, Christopher Reichley, Pamela Lawhead, Yixin Chen

Background and Objective

Steady State Visual Evoked Potential (SSVEP) is the brain's natural electrical potential response for visual stimuli at specific frequencies. Using varied frequency flashing lights as stimuli will cause the SSVEP to become entrained at the same frequency, thereby allowing determination of the subject's visual focus [1,2]. The efficacy of an SSVEP BCI depends on the speed and the accuracy with which it distinguishes the SSVEP activity reflecting user attention from the background noise [3]. Because the SSVEP has the same fundamental frequency as that of the visual stimulus, the stimulus is expected to be as noise-free as possible. Bin et al. [4] showed harmonic frequencies in the SSVEP at a reduced magnitude can be useful for determining the stimulated frequency [5] in the case that they are evoked from the fundamental stimulating frequency and are not artifacts of the original signal. In this study, we compare the SSVEP responses of three Fourier series generated stimuli: square wave, triangle wave, and sine wave. It is clear that the nature of non-sine waves, although delivering strong stimuli at the fundamental frequency, also reduce signal to noise ratios with unwanted harmonics. In this paper, we examined the SSVEP evoked by the three waves, and compared the strengths of the evoked harmonics as a function of wave type.

Methods

EEG was recorded at a sampling rate of 1.5kHz using a light emitting diode connected to an HP function/wave generator. We examined stimuli between 8Hz and 17Hz at 1Hz intervals. We recorded the SSVEP for square, triangle, and sine waves. The EEG was recorded with one channel over the occipital cortex. The distance between a subject and the LED was one meter.

Results

Square waves generate stronger harmonics at 3*f (stimulating frequency) than triangle waves in SSVEP. Sine waves delivered the smallest harmonics in the SSVEP because of reduced 3*f harmonics in the stimulating signal.

Discussion and Conclusions

The observed variations on the SSVEP harmonics correlate with the spectral characteristics of the three stimuli: the SSVEP induced by a sine-wave light source has the smallest 3*f harmonics. Keywords: SSVEP, Square wave, Triangle wave, Sine wave, Harmonic [1] Morgan S.T., Hansen J.C., Hillyard S.A., (1996). Selective attention to stimulus location modulates the steady-state visual evoked potential. Neurobiology, 93, 4770-4774. [2] Muller M.M., Hillyard S.A., (1997). Effects of spatial selective attention on the steady- state visual evoked potential in the 20-28 Hz range. Cognitive Brain Research 6, 249-261. [3] Allison B., Sugiarto I., Graimann B., Gräser A., (2008). Display optimization in SSVEP BCIs. Workshop on Brain-Computer Interfaces for HCI and Games. 4 pages. [4] Bin G., Gao X., Yan Z., Hong B., Gao S., (2009). An online multi-channel SSVEP-based brain-computer interface using a canonical correlation analysis method. Journal of Neural Engineering, 6 046002 (6pp). [5] Krusienski D., Allison B., (2008). Harmonic coupling of steady-state visual evoked potentials. Proc. 30th Annual International Conference of the IEEE Engineering in Medicine and Biology Society, 5037-5040.

T-3 EEG Processing and Robotic Bio-Feedback Interfaces

Christopher Reichley*, Aik Min Choong , Fei Teng, Dwight Waddell, Pamela Lawhead, Scott Gustafson, Yixin Chen

Background and Objective

Studies in the field of Brain/Computer interface have shown a strong correlation between biofeedback to alter brainwave frequency ratios and the improved ability to focus. Developing an interface between modular devices to create a reward feedback system based on maintaining desired brainwave frequency ratios will allow for electroencephalographic (EEG) performance training to extend beyond clinical settings and to be integrated into the field. This study focuses on work done to develop and implement a portable unit that receives digitized EEG signals, logs them, evaluates their spectral content, and then provides feedback to subjects. The novelty of this study is that the feedback is used to control physical devices rather than more commonly used virtual objects. The unit is capable of wireless communication with both the sensor digitizing unit and the external reward systems, i.e. a mobile robotic vechicle. This standardized system can be used to provide multiple training configurations each dependent upon the environment and requirements of an individual trainee.

Methods

In conjunction with the Brain/Computer Interface research group at the University of Mississippi where the development of a bluetooth compatible, modular EEG sensor unit has recently been completed, a software application is designed for data collection and processing. Initial implementation involves solid state netbook laptop software with additional research in multiple mobile architectures (iPhone, Blackberry, HTC Droid, etc.). The prototype system receives a wireless data stream from the sensor unit and processes the collected data. The data is further processed based on established EEG bandwidths which correlate with particular behaviors thereby determining when reward reinforcement should occur. When a reward scenario is achieved, two categories of reinforcement can occur: wireless communication adjusting the behavior of the robot (or other outside device), or direct visual feedback on a processing display unit.

Results

The main research goals of this prototype are to outline the metrics for determining the reward schedule, communication with modular devices, and data cataloging for future study. The successful implementation of this project provides the ability to gather clinical grade data results from subjects in non-clinical settings. The external environment plays a role in the results and potentially the long term translation of the training. Using a modular device not restricted to a laboratory environment will allow EEG training to be realized in real world settings. Additionally, the use of a tangible and interactive objects may potentially increase training efficacy compared to conventional EEG training.

Keywords

Brain-Computer Interface, Mobile Devices, Robotics, EEG