BCI Practical : Possible Projects

The final part of the BCI Practical course is to make a complete working BCI system. For this you can suggest your own idea, or take one of the ideas below as a starting point and then develop it into a full BCI system.

Cybathalon 1 : Mental Tasks Identification

For the Cybathalon project we will be recruiting a paralyzed patient to take part as our pilot. The pilot will then be required to 'train' themselves to produce as strong as possible a brain response to control their avatar in the race and then 'win' the competition. An outstanding question is what mental task the pilot should train on, and how to identify the right one. The BCI literature has a few studies comparing different mental tasks, and many such tasks have been identified. For this project the team would need to develop a framework for evaluating different possible tasks and a criteria for selection of tasks which together maximize the pilots eventual performance in the competition. Note, the tasks should not just be selected for best 'untrained' performance but to maximize the eventual trained performance. Issues to consider include:

1) Initial performance

2) Ease of training – i.e. is it easy for the pilot to practice the task

3) Ease of learning – i.e. can the pilot quickly improve performance on this task

4) Interaction with the other task – i.e. does the task set work well together, without too much interference

5) Fun – that is, is it fun for the pilot to do (otherwise he won't practice)

[1] Curran, Eleanor A, and Maria J Stokes. "Learning to Control Brain Activity: A Review of the Production and Control of EEG Components for Driving Brain–computer Interface (BCI) Systems." *Brain and Cognition* 51, no. 3 (April 2003): 326–36. doi:10.1016/S0278-2626(03)00036-8.

Cybathalon 2: Development of BCI user training paradigms

For the Cybathalon project we will be recruiting a paralyzed patient to take part as our pilot. The pilot will then be required to 'train' themselves to produce as strong as possible a brain response to control their avatar in the race and then 'win' the competition. An outstanding task is how we should present the feedback to the pilot in order to maximise the rate at which they achieve control of the BCI. Current BCIs, such as [1,2], tend to use simple training paradigms where feedback is given visually, rapidly based on the measured brain signal. Recent research [2,3] has pointed out that this may not be the best approach to facilitate rapid skill acquisition. This project would investigate the effect of different feedback parameters on the ability of the user to learn to control the BCI, by for example varing the rate at which feedback is given or the accuracy of the feedback, or by providing agumented feedback including information on other factors influencing BCI performance – such as presence of artifacts.

[1] LaFleur, Karl, Kaitlin Cassady, Alexander Doud, Kaleb Shades, Eitan Rogin, and Bin He. "Quadcopter Control in Three-Dimensional Space Using a Noninvasive Motor Imagery-Based Brain–computer Interface." *Journal of Neural Engineering* 10, no. 4 (August 1, 2013): 046003. doi:10.1088/1741-2560/10/4/046003.

[2] Wolpaw, Jonathan R., and Dennis J. McFarland. “Control of a Two-Dimensional Movement Signal by a Noninvasive Brain-Computer Interface in Humans.” *Proceedings of the National Academy of Sciences of the United States of America* 101, no. 51 (December 21, 2004): 17849–54. doi:10.1073/pnas.0403504101.

[3] Lotte, Fabien, and Camille Jeunet. “Towards Improved BCI Based on Human Learning Principles.” In *Brain-Computer Interface (BCI), 2015 3rd International Winter Conference on*, 1–4. IEEE, 2015. http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=7073024.

[4] Schumacher, Julia, Camille Jeunet, and Fabien Lotte. “Towards Explanatory Feedback for User Training in Brain–Computer Interfaces.” In *IEEE International Conference on Systems Man & Cybernetics (IEEE SMC)*, 2015. https://hal.inria.fr/hal-01179329/file/IEEESMC_Paper_predictors.pdf.

Cybathalon 3: Robust Signal analysis systems

For the Cybathalon project we will be recruiting a paralazed patient to take part as our pilot. The pilot will then be required to 'train' themselves to produce as strong as possible a brain response to control their avatar in the race and then 'win' the competition. One question is how well the developed system will cope with the many artifacts we are likely to encounter in the competition environment – not only is the external environment likely to be highly noisy due to the audience, cameras, electronics, etc, and are we likely to have strong subject-related artifacts as they move in response to the task and their performance, but we are likely to see many brain related artifacts, as they respond to aspects of the control, e.g. when they are happy+winning, sad+loosing, fustrated by poor control etc. Dealing effectively with these artifacts is an important part of making a robust system, this project would be to develop a system which is as robust as possible to these possible artifacts. There are many possible ways to do this (such as developing special case filters for each artifact type). However, one general artifact-independent approach would be use use an adaptive feature normalization system similar to proposed in [1] to cope with these artifacts.

[1] Reuderink, B., J. Farquhar, M. Poel, and A. Nijholt. “A Subject-Independent Brain-Computer Interface Based on Smoothed, Second-Order Baselining.” In *2011 Annual International Conference of the IEEE Engineering in Medicine and Biology Society,EMBC*, 4600–4604. IEEE, 2011. doi:10.1109/IEMBS.2011.6091139.

Cybathalon 4: Zero-training adaptive classification systems

For the Cybathalon project we will be recruiting a paralyzed patient to take part as our pilot. The pilot will then be required to 'train' themselves to produce as strong as possible a brain response to control their avatar in the race and then 'win' the competition. This subject training based approach is used to maximize final signal strength during the event. However, and open question (related to Project 1) is how do we adapt the system to the user on subsequent training days. Should we fix the analysis pipeline and leave it to the user to learn to make a strong signal? Or should we adapt each day to the changing environment by completely re-training the system. The latter option however runs the risk that the user is unable to learn as the target signal is changing too much every day. Also the time taking re-calibrating the system every day is frustrating and reduces the time the user spending learning to make stronger signals.

An alternative is to have the system automatically adapt every day to the changes. A feature normalization technique such as suggested in Cybathalon 3 is one approach to this. However, feature normalization does not adapt the classifier to the changes in data noise, thus an additional step to adapt the classifier may be necessary. Ideally, this should be calibration free, in that this happens automatically during normal usage without requiring a new calibration (i.e. cueued) phase. In the BCI literature this question of adapting the classifier is called 'covariate shift' and numerous possible solutions have been proposed [1],[2]. This project would develop an experiment to record data containing such shifts and identify algorithms to address this issue.

[1] Bickel, Steffen, Michael Brückner, and Tobias Scheffer. "Discriminative Learning Under Covariate Shift." *J. Mach. Learn. Res.* 10 (December 2009): 2137–55.

[2] Sugiyama, Masashi, Matthias Krauledat, and Klaus-Robert Müller. "Covariate Shift Adaptation by Importance Weighted Cross Validation." *The Journal of Machine Learning Research* 8 (2007): 985–1005.

[3] Llera, A., V. Gómez, and H. J. Kappen. "Adaptive Classification on Brain-Computer Interfaces Using Reinforcement Signals." *Neural Computation* 24, no. 11 (July 30, 2012): 2900–2923. doi:10.1162/NECO_a_00348.

Prediction of when users are aware vs un-aware of a visual stimulus

Identifying neural correlates of conscious (aware) vs. unconsciously (unaware) perceived stimuli is a classical and current area of research in neuroscience, see [1], [2]. These studies have revealed some consistent experiment designs (masking) and evoked responses (Visual Awareness Negativity) which have been shown to correlate to visual awareness of the stimuli. An interesting question is "can these evoked responses be used to **predict** accurately which stimuli the subject is aware of?". In BCI terms this would correspond to can be from the brain response predict if the user was aware of the stimuli – such a prediction would validate that the evoked response is causally related to awareness. Further, such a system is potentially useful in many potential BCI applications where tracking subjects awareness of their environment is important, e.g. alertness monitoring in air-traffic-control.

[1] Koivisto, Mika, and Antti Revonsuo. "Event-Related Brain Potential Correlates of Visual Awareness." *Neuroscience & Biobehavioral Reviews*, Special Section: Developmental determinants of sensitivity and resistance to stress: A tribute to Seymour "Gig" Levine, 34, no. 6 (May 2010): 922–34. doi:10.1016/j.neubiorev.2009.12.002.

[2] Railo, Henry, Mika Koivisto, and Antti Revonsuo. "Tracking the Processes behind Conscious Perception: A Review of Event-Related Potential Correlates of Visual Consciousness." *Consciousness and Cognition* 20, no. 3 (September 2011): 972–83. doi:10.1016/j.concog.2011.03.019.

Gaze-locked ERP analysis

Event related potentials (ERPs) are brain signals with consistent location and polarity locked to a particular reference event. ERPs have been widely used in BCI and basic neuroscientific investigations. However, one limitation of using ERP methods is defining a consistent time reference – thus to date ERP analyses have been mostly limited to referencing to the onset time of particular stimuli. This is fine for single stimuli at the center of the subjects field of view, however most natural tasks have stimuli out of the central field-of-view – thus using stimulus onset as a time reference may give poor results as stimuli may be visible for some time before they are processed by the subject. A recently proposed alternative [1,2] is instead to reference to eye-movements, specifically the time at which the eye ends it's saccade and first fixates on the target location. This has been shown to give much improved ERPs. It further opens the opportunity for more general perception experiments – e.g. in a where's wally style where the participant is presented with a complex visual scene and eye-locked analysis allows the determination of when the user first recognizes a target symbol. This ability has potential applications both for traditional BCI communication applications (e.g. detect when the user has fixated on the letter they want) and more novel applications, such as for detecting when a user has identified and processed a particular target stimulus such as in language learning [2].

This project is to investigate this possibility by;

1. developing a signal-analysis framework for recognition of fixation's and generation fixation events for ERP analysis and classification
2. developing an experiment to validate this approach, e.g. in a visual target search task

[1] Dimigen, O., Sommer, W., Hohlfeld, A., Jacobs, A. M., & Kliegl, R. (2011). Coregistration of eye movements and EEG in natural reading: Analyses and review. Journal of Experimental Psychology: General, 140(4), 552–572. doi:10.1037/a0023885

[2] Peot, M., Aguilar, M., & Hawkins, A. T. (2014, June 24). EEG-based acceleration of second language learning. Retrieved from http://www.google.com/patents/US8758018

Free task Neurofeedback – what can be learned by neurofeedback training?

Neurofeedback training allows a subject to learn to intentionally modulate features of the measured brain activity. To date most neuro-feedback research has focused on brain signals which are relatively spatially and spectrally localized and previously known to be correlated with certain behavioral measures, such as motor-strip mu-power correlating to imagined or executed limb movements. In principle the basic process of neuro-feedback (or any feedback/operant-conditioning paradigm) does not have to be restricted to such limited features. It is an interesting question what are the limitations of this training, that is to identify what types of signal features control can be learned (and how fast) and for which this is not possible.

Particularly interesting features to investigate are those associated with simultaneous activation of spatially separated brain regions. Inducing such simultaneous activation has potential therapeutic applications in helping to strength the connection between targeted regions via. neural plasticity induced by the co-activation. Such an ability is potentially useful in many syndroms associated with poor connectivity.

This project would be to:

a) identify a set of brain signals to test, ranging from class NF targets to more novel ones

b) develop a neurofeedback training regime for the brain signal

c) train 1+ subjects to intentionally control their brain signals

d) evaluate the relative difficulty of learning to control the different signal targets

Brains-on-fire (v3)

Frets-on-fire (FoF) is an open-source guitar-hero clone, see **fretsonfire**.sourceforge.net, written in

Python. Previous projects have shown that 'air-drumming' generates brain signals, specifically the Lateralised readiness potentials (LRPs),which can be detected and classified with reasonable accuracy in an off-line setting. This project would extend this work to include and on-line aspect – allowing the subject to actually play the game!

Things to think about:

- modifying the game to allow BCI control – this has already been done in previous projects. Has already been done using a socket protocol, should be changed to use the buffer interface (available in Python).
- Game timing should be slow enough to make the BCI work, fast enough to be a fun game
- BCI : FoF is an asynchronous game – users can hit buttons any time they want! Thus we either; a) need an asynchronous BCI, or b) need to 'cheat' an only look at the brain data when a button press is needed?

Mindreading Game / Rapid serial visual presentation

The brain-fingerprinting system allows the identification of criminals by their brains unique reaction to previously seen salient stimuli [1]. Further the Rapid serial visual presentation (RSVP) or cortically coupled computer vision system allows users to rapidly identify targets of interest by their visual systems recognition of target properties, using the same brain signature as used in brain-fingerprinting. A more frivolous use of the same technology would be for a simple "this is your card" magic trick, where the user initially picks an image at random from a set of possible images and then the computer rapidly displays these images to the user and identifies the image they picked from their brain response. A more sophisticated version of this could be made by combining with an n-back task, where the user is given 2 or 3 or 4 targets to remember which are then presented in a RSVP fashion for the computer to identify which were the users targets - (one could then claim that this could be used to train/assess the users memory performance / visual processing speed). Design goals:
* Simple specification of the set of images to be searched through
* Minimal initial system training/calibration phase
* Nice GUI for the user to indicate their selections
* scoring system to make it fun?

[1] L. A. Farwell, "Brain fingerprinting: a comprehensive tutorial review of detection of concealed information with event-related brain potentials," Cognitive Neurodynamics, vol. 6, no. 2, pp. 115–154, Apr. 2012.

Is a delayed hold necessary for the generation of LRPs

The Lateralised Readiness Potential is an ERP generated whenever a subject intends to move one limb whilst not moving the other. Interestingly, this ERP is detectable before the movement actually begins, and there is some evidence it can be detected even before one is even aware of the intention to move! However, most experiments to detect the LRP use actual movements to detect them. This allows for a precise time-lock for the movement start and hence improves movement detection. For imagined movements detection of LRPs is more challenging - with many studies being unable to detect them. However, there is some evidence that one reason for this difficulty is the poor time-lock in imagined movement onset times, and that by addressing that, by for example using a delayed hold task where the user is given a countdown to movement start, can allow the detection of LRPs for imagined movements in Tetraplegics [1]. This experiment would attempt to replicate this result to answer the question if LRPs are evoked and detectable in imagined movement. If successful, this could allow the one to improve the performance of IM BCIs by including a 3rd signature as well as the more conventional ERD and ERS.

[1] L. Kauhanen, P. Jylänki, J. Lehtonen, P. Rantanen, H. Alaranta, and M. Sams, “EEG-Based Brain-Computer Interface for Tetraplegics,” Computational Intelligence and Neuroscience, vol. 2007, pp. 1–11, 2007.

Hybrid-BCI -- visual speller using eye-blinks, EOG and P300 to detect letters faster

The definition of BCI we have used so far specifically excludes use of the peripheral nervous system. However, for many applications, such as gaming, rehabilitation, communication for non-completely-locked-in patients, some muscle movement is still possible and can be used to significantly improve the performance of the BCI. In this project you will build such a hybrid BCI [1] for the visual matrix speller paradigm. Specifically, you will modify the basic speller such that eye signals can be used to indicate the users letter choice – either by blinking when the appropriate letter is highlighted, and/or by decoding the EOG signal to give and indication of where the users eye's are pointing. Combining these abilities with the conventional P300 signal we expect to massively improve performance for patients with some residual eye-control, whilst allowing the same paradigm to be used for patients with no-eye signals.

[1] G. Pfurtscheller, B. Z. Allison, C. Brunner, G. Bauernfeind, T. Solis-Escalante, R. Scherer, T. O. Zander, G. Mueller-Putz, C. Neuper, and N. Birbaumer, “The Hybrid BCI,” Front Neurosci, vol. 4, Apr. 2010.

Multi-tap for multi-class

Imagined movement of one hands is very commonly used for BCI control. However, with only 2 hands the number of possible decisions is limited. By choosing the sequence of hand movements, e.g. Left-left-right, we can increase the number of possible decisions. Additionally, there is some evidence that such movement alteration could *increase* BCI performance. This project would investigate this possible method of increasing the flexibility of movement based BCIs.