PARAMETER STUDY FOR IMPROVING TRAINING QUALITY IN BRAIN-COMPUTER INTERFACE

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Abstract
Control of electroencephalograph signals (EEG) when different mental tasks are carried out, would allow a communication option for people with serious motor function problems. This system is a brain computer interface (BCI). The difficulty of controlling EEG signals requires a suitable training protocol, motivating and helping subject, avoiding learning retirement. To set parameters that could establish a training protocol, ten untrained subjects participated in seven training sessions. Objective and subjective measures were taken, based on the recording of other psychophysiological signals, attention tests and questionnaires. The obtained results show how important it is to take these measures, and also allow us to reject some elements and to emphasize other elements that can influence the training quality.

Key Words
Brain Computer Interface, Electroencephalograph signals, Training.

1. Introduction
The development of an interface between the human brain and an artificial system, such as a computer, is not a recent aim [1]. A brain-computer interface (BCI) is based on the analysis of the electroencephalograph signals (EEG) recorded during some mental activities to control an external device. One of its main uses is in the field of medicine and especially in rehabilitation. It helps to establish a communication and control channel for those people with serious motor function problems but without brain function disorder.

BCI is based on the ability of people to control some features of EEG activity which includes a variety of different rhythms that are identified by their frequency and their location, and are associated with various aspects of brain function. Performance of BCI will depend especially on the ability of the subject to control their own EEG pattern. To this end, it is necessary to provide suitable training, which can sometimes go on for several months [2], being very important to provide some type of feedback allowing subjects to know their progress [3],[4], [5].

Nowadays, the vast majority of researchers in the BCI field work to improve signal processing methods and translation algorithms. All of them put emphasis on the importance of developing training methods based on biofeedback techniques that would improve human performance [3], [4].

The purpose of BCI is not to select a subject with good EEG control ability and to train them to get high classification accuracy. No matter how sophisticated feature extraction procedures and translation algorithm, BCI will not be useful if it cannot be used by their aim user: subjects with serious motor function problems. If an inappropriate training is added to the difficulty of controlling EEG signals, the result will be frustration and retirement of many subjects. To avoid this problem, working on training techniques is necessary.

Few papers deal with training techniques, especially those related to the advantages of providing continuous or discrete feedback [5],[6]. However, a lot of different parameters must be considered to define a suitable training protocol. As well as the mental tasks achieved by subjects, some of these parameters are related to the training paradigm, such as: i) duration, repetitiveness and pause between trials, ii) the mental activities’ duration, and iii) the session’s duration. Others of these parameters are related to presentation and type of feedback provided: i) session with or without feedback, ii) continuous or discrete feedback, and iii) type of feedback.

To obtain conclusions, not only is it possible to select trained subjects or to consider accuracy classification as the only parameter as suggested in [3], it is also necessary to explore the influence of all these parameters on attention ability, motivation and subject concentration, very closely related to their physiological state and learning process. To this aim, objective and subjective measures should be taken [7], based on the record of other psychophysiological signals, attention tests and questionnaires allowing subjects to describe their own impressions. All elements must be evaluated on trained and untrained subjects.
As first reference, our work is based on the training protocol and BCI system (Graz BCI) now used by the G. Pfurtscheller group [8], one of the most prestigious groups with the greatest contribution to the BCI field. Their work is based on discrimination between two mental tasks, especially between imagination of right and left hand movement [9], [10], [11]. Recently they discriminated between imagination of right-hand and both-feet movement [4].

The discrimination between these mental tasks is based on amplitude changes of mu (7-13Hz) and central beta (18-26Hz) rhythms, focused over sensorimotor cortex and recorded from the scalp over central sulcus. These rhythms, and especially mu rhythms, display an amplitude attenuation or event-related desynchronization (ERD) over the contralateral hemisphere [9].

The purpose of this paper is to carry out a first and rigorous study of possible parameters that could influence the training followed by a subject. Contrary to the vast majority of papers, our study will be done with untrained subjects. We will investigate possible factors that could affect the subject training, through objective and subjective measures. With this study we intend to help develop training methods to enable subjects to gain and maintain EEG control.

Section two describes the followed methods and used materials. In section three, the obtained results are presented. Section four discusses the results of the study and section five presents the conclusions.

2. Methods and Materials

2.1. Subjects

Ten subjects, telecommunication engineering students of the University of Malaga, 5 female (S3, S5, S6, S7 y S10) and 5 male (S1, S2, S4, S8 y S9), of ages 21-26, participated in this study. None of them had previous experience in BCI, and all were selected independently of their initial ability to control EEG signals. Subjects participated voluntarily, and one of them was left-handed.

2.2. Trial time and training paradigm

During the experiment, the subject was instructed to watch the black screen in front of them, to stay as relaxed as possible, to think of nothing in particular, and to carry out some trials. The duration of each trial was 8 seconds, the timing is shown in figure 1. Trial began with the presentation of a red cross in the centre of the screen, followed by a short beep at 2s. At 3s, and for 1.25s, a green arrow appeared on top of the cross, and depending on its direction, the subject was instructed to imagine continuous movements of the right or left hand until the end of the trial. In the case of a feedback session, at 4.25s the arrow disappeared and then feedback stimulus was presented for 3.75s. This consisted of a blue horizontal bar, which extended more or less to the right or left according to the classification result. At 8s, the trial was finished returning to a black screen, and started again after a break ranging between 0.5 s and 3s.

Each session consisted of 4 experimental runs of 40 trials (20 “left” and “20” right” trial). Training protocol consists of 7 sessions, 2 without feedback and 5 with feedback, with a ratio of 3 per week:

- Session 1 without feedback: Data are used to set up classifier parameters of the following feedback sessions.
- Session 2 and 3 with feedback.
- Session 4 without feedback: Data are used to set up classifier parameters of the following feedback sessions.
- Session 5 and 6 with feedback.
- Session 7 with feedback: Data of session 6 are used to set up classifier parameters.

Because of subjects inexperience on BCI, they were informed what the study was about, and how EEG signals were affected by both mental tasks. Before starting training protocol, subjects participated in a preliminary session without feedback to familiarize with BCI system and paradigm. In this session, subjects made a right-left hand movement, depending on arrow direction. For next sessions, subjects were instructed to keep as relaxed as possible to avoid any muscular and ocular movement which could contaminate EEG signals.

At the end of each session, subject had to complete a questionnaire to transmit their impressions. To measure concentration and attention capacity of subjects, very important for correct learning, they took a trial based on the Toulouse-Piéron test [12].
2.3 Signal recording

As with Graz BCI, the EEG was recorded from two bipolar channels with electrodes placed over the right and left hand sensorimotor area. Actives electrodes were placed at 2.5 cm before and 2.5 cm posterior to electrode position C3 and C4 according to the 10/20 international system. Reference electrode was placed at FPz position. Signals were amplified by a 4 channel Coulborn V75-08 amplifier and then digitalized at 128Hz.

Beside EEG signals, to get objective measures about subject state, other psychophysiological signals were recorded. In this study, for off-line analysis, the recorded signals were heart rate (HR) and galvanic skin response (GSR), electrodermal activity, typical to measure stress level and to establish biofeedback relaxation techniques [13]. HR was recorded by a photoplethysmograph Coulborn V71-40 with a sensor placed on the left thumb. GSR was recorded by an impedance measurement Coulborn V71-23, with two disposable electrodes placed on the middle and index finger tips of the right hand.

2.4 Signal processing

System development and signal processing were made in MATLAB. To provide feedback, the chosen process was one suggested in [4]. This consists of estimating band power of each channel in predefined, subject specific frequency bands in interval of ½ second. Then, power parameters are linearly combined by a weight vector obtained by linear discriminant analysis (LDA) [6], [14]. The classification result is converted to the length of feedback bar, and it is updated each 4 samples, to provide feedback as continuous as possible.

3. Results

3.1. Error percentages

Figure 2 presents the average classification results (error rate) between sessions during feedback period, for all 10 subjects. The obtained results allow two different groups to be established. Group A, made up of 6 subjects (S1-S6), whose curves (fine lines) stay constant around 50%, showing no progress learning. Group B, made up of 4 last subjects (S7, S8, S9, S10) presents an error rate decrease (thick lines), as a result of good classification in some sessions. Except for S7 who shows a favourable progress while feedback is provided, the 3 other subjects respond better during the first two seconds of feedback period, finding it hard to maintain concentration during the whole feedback period.

In general, the results do not seem to vary between female and male. Subjects do not show constant improvement with the increase of sessions. A lack of learning has been noticed. The first session without feedback has not permitted a reliable weight vector for 5 to 6 subjects of group A. As a consequence, length bar do not depend only on EEG control ability of subject, and feedback might not carry out its function. For these subjects, additional sessions without feedback seems more suitable and permits a more suitable weight vector.

![Figure 2: Average error rate between session of each subject.](image)

![Figure 3: ERD/ERS curves of subject S3 (Session 5).](image)
3.2 ERD/ERS

Based [6], [9], ERD/ERS was calculated for each session. Reference interval was defined between 0.5s and 1.5s. Studying these curves, for 3 subjects (S1, S2 and S5), an unstable and poor desynchronization was observed during feedback control. These subjects would need longer training period to learn to desynchronize EEG signals with imagination of limb movement. The rest of the subjects showed, from the beginning of sessions, a clear desynchronization during feedback period compared to relax period (0s to 3s), but this was produced in both hemisphere independent of the mental task, as we can see in the example of figure 3 for subject S3.

Difficulty of subjects in producing contralateral desynchronization, could suggest that these mental tasks are not suitable for any subject to learn to control a BCI system.

3.3. Objective measures

At first, the main reason to record psychophysiological signals were to allow us the identification and the study of possible strange behaviour. Changes of heart rate throughout the sessions and for each subject were studied, and we did not notice abnormal behaviour. The results showed insignificant changes, matching with a normal response. In future works, it could be interesting to study heart rate variability (HRV).

Regarding galvanic skin response, some subjects presented more activity than others. However in all of them, high difference responses between sessions with and without feedback, were noticed. Figure 4 shows an example of GSR activity of one subject (S5). Each curve represent the differential GSR average (GSR minus its global mean) of all trials for each session. Continuous curves represent feedback sessions and dot curves, sessions without feedback.

In feedback sessions, a greater activation of electrodermal response is observed during feedback period. These results suggest that feedback seems to help to maintain subject attention in their mental activity. In sessions without feedback, attention seems to decrease, because no visual stimulus is presented on screen. This suggest that electrodermal activity might be used as an objective measure of the mental activity carried out by subject.

3.4. Subjective measures

The subjective measures consisted of a Toulouse-Piéron test and a questionnaire.

Subject had to value (0 to 10) some questions related to their general state and session impressions.

-Subject state: 1) Eyestrain, 2) Headache, 3) Trouble because of electro-cap, 4) Tiredness, 5) Mental fatigue.
Once evaluated the results shown in figure 5, we obtained the following conclusion. The vast majority of subjects finished sessions with a little eyestrain (average value 4). To improve this, it could be interesting to research other options of visual feedback presentation, as suggested in other paper [5]. Training paradigm does not seem to produce neither headache nor trouble caused by electro-cap. Tiredness and mental fatigue vary noticeably between subjects, but values are not very high. The required effort to subjects does not seem too important. There was no direct correlation between sessions with and without feedback, or between subjects of group A and B has been noted.

Session impression: 1) Long session, 2) Entertaining session, 3) Interesting session. Figure 6 shows the average results by subject and by session.

For each question, the evaluation of each subject has been similar, proving there is no relation between these parameters and the classification results. Without being excessive, the session duration turned out to be a bit long. It might be desirable to reduce the number of experimental runs from 4 to 3. In fact, many subjects thought that during the last experimental run, it was more difficult to concentrate. Regarding the entertaining and interesting sessions, the average value is around 5. Although this is an subjective value, the impression is that the session could be more entertaining. In the 3 questions, a difference between session without feedback and session with feedback is noticed. Session with feedback seems less long and more entertaining and interesting. This is an important conclusion because, even though feedback could result frustrating, it can make sessions more entertaining. In this study, a continuous feedback has been used, and the constant bar variation from one side to the other for subjects with poor control had, in general, a negative effect. To avoid this, it could be beneficial to present during the first training sessions a delayed and discrete feedback, like the G. Pfurtscheller group did in their first researches [9],[10],[11], achieving motivation without continuous frustration.

4. Discussion

The results obtained in this study show how important it is to improve training methods, to evaluate other parameters apart from classification results. The results also allow us to reject some elements and to emphasize other elements that can influence the training quality.

The followed training protocol [8] does not seem too appropriate for untrained subjects. In only 7 sessions, and with these mental tasks (imagination of right and left hand movement), subjects do not learn to produce contralateral desynchronization, causing them frequent frustration. In order not to discourage subjects, it could be advantageous to start training with two mental tasks easier to discriminate. These mental tasks could be relaxing and movement imagination, because a clear desynchronization between them, has been noticed in many subjects. It is important to suitably adjust the training protocol to control the capacity of each subject. It seems advisable to increase the number of sessions without feedback to guarantee suitable weight vector.

The subject opinion is very significant. One of the most important questions is the continuous feedback effect on subjects. In general, continuous feedback makes sessions more entertaining, but its effects are very variable and depends on subjects. It has a positive reinforcement if subject has some control, but if the subject does not, the effect could be frustrating, being more advisable to be left out, or to use a delayed and discrete feedback.

5. Conclusion

One of the most important uses of a BCI system is to establish a communication channel for people with serious motor function problem. However, BCI will not be useful
if the carried out training is given up, because of tiredness, frustration and lack of motivation. The study carried out has shown that training protocols must not be chosen at random. On the contrary, in many cases, they must adapt to the subject to be effective. Feedback is necessary and makes sessions more attractive and interesting, however, we should try to make its effects always positive. For this, we suggest to improve presentation techniques, the use of techniques based on 3D representation being a good option – as proposed in other papers [15], [16] - achieving a more immersive and motivating effect.

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References


