Radboud University, Nijmegen

Bachelor degree thesis in Artificial Intelligence

Mario vs. Boring

Generating stronger potentials by playing games.

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Abstract

Training to use brain-computer interfaces (BCI) can help several groups of patients, e.g., paralysed patients and stroke patients. Unfortunately, training often takes a long time and can get boring after a while. By letting two groups do the same training program, with a different feedback, this research aims to answer the question of whether more motivational feedback can speed up the learning process. One group gets boring feedback, consisting of three ellipses, with the goal of moving one of the ellipses to the correct side, while the other group gets a part of the famous Nintendo game Mario with the goal of collecting coins. Although, it is possible to increase subject motivation with different feedback, the results show there was no significant increase in subject learning. A possible reason for this could be the small sample size ($N = 4$). Future research should find out whether this is the case or motivation just does not effect the speed of subject learning.

Contents

1 Introduction

A brain-computer interface (BCI) is a system which allows users to communicate information about their mental state without the use of the peripheral nervous system. So it provides a way to communicate with signals directly measured out of the brain, without the use of any body or face movement.

It is possible to learn how to control a BCI. That is, to learn how to consciously alter your brain activity. Not all BCIs are learnable in this manner, but one sort that is, is the (imagined) movement based BCI [12]. This training process can take weeks or even months [16]. Even due to this long training period, it can be beneficial for certain individuals to learn to use a (imagined) movement based BCI.

First of all, BCI can give paralysed or locked-in patients a way to communicate with the outside world [16]. Locked-in patients are patients that are aware but cannot move or communicate verbally, because of the complete paralysis of (nearly) all voluntary muscles (sometimes these patients are capable of eye movement) and have therefore no other means of communicating. By training with the BCI, communicating through the BCI can get faster and less erroneous, because it can reduce the noise-to-signal ratio, by increasing the strength of the signal. The noise-to-signal ratio expresses how strong the noise in the signal is compared to the signal you are interested in. This ratio is defined as the quotient of the standard deviation of the noise to the expected value of the square of the signal [11]. Currently this ratio is very high, which makes it harder for the BCI to correctly predict the intentions of the subject. By training subjects their signal can become stronger, which will reduce the noise-to-signal ratio and therefore improve the accuracy of the BCI.

A second group that can benefit from BCI training is stroke patients. Still a lot of research has to be done on this subject, but it is hypothesised that using BCI training can help patients activate those neurons that are still alive, but lost a lot of connections because of the stroke. These neurons normally do not get a lot of activation and without enough activation they eventually die. By targeting these neurons with a BCI and give positive feedback when they are activated, the patient can learn how to consciously activate these neurons, this activation leads to less dying neurons. Eventually, this can even lead to new connections between neurons. Therefore, BCI training would improve the rehabilitation process. There is some evidence to support this hypothesis [2, 3].

To have effective learning, some sort of feedback to the user about their brain signals is needed. This thesis discusses whether more motivational feedback increases the learning performance, i.e., do motivated subjects learn faster. So specifically this thesis aims to answer the question: 'Does motivation improve performance in learning how to use a movement based brain-computer interface?' To answer this question the group of subjects will be split in two and one of these groups gets a more motivational feedback than the other group. It is hypothesised that the question can be confirmed and thus that the strength of the brain signal of the group with the motivational feedback increases more than the strength of the brain signal of the group with the boring feedback. The way the strength of the brain signals is assessed is described in section 2.7.

The thesis is split in five sections, starting with some literature research, followed by the methods used in the experiment. Then the results of the experiment are described and after that there is a discussion, followed by the conclusion of the research.

1.1 Movement in BCI

The BCI used in this experiment is movement BCI. The participants are asked to move one of both hands. Moving gives three measurable reactions in the brain. First, a readiness potential (RP), a slow increase in negativity in the contralateral precentral region just before starting the movement can be measured [7]. After the RP an event-related desynchronisation (ERD) will occur. This is a desynchronisation of the μ- and β-waves, best measurable around 10 to $24\,Hz$. An event-related synchronisation (ERS) will follow the ERD. In the ERS the μ- and β-waves get stronger and overshoot the level they have in rest. After the ERS the μ- and β-waves return to their normal level [15]. Both the ERD and ERS occur in the motor area on the contralateral side of the brain, thus right hand movement will produce an ERD and ERS in the left side of the brain, while left hand movement produces these signals in the right side of the brain.

The BCI in the experiment will use the ERDs. To measure the ERDs for hand movement you only need two electrodes, the C3 and C4 electrode [14]. These electrodes target exactly the part of the motor cortex where hand movement is controlled. In Figure 1 the location of these areas is shown. In Figure 2

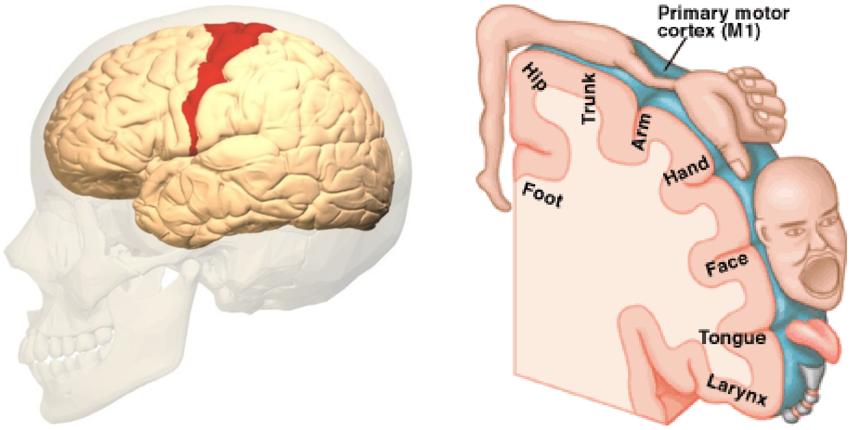

Figure 1: Location of the primary motor area in the middle brain (left picture) and the partition of this motor area, between the separate body parts.

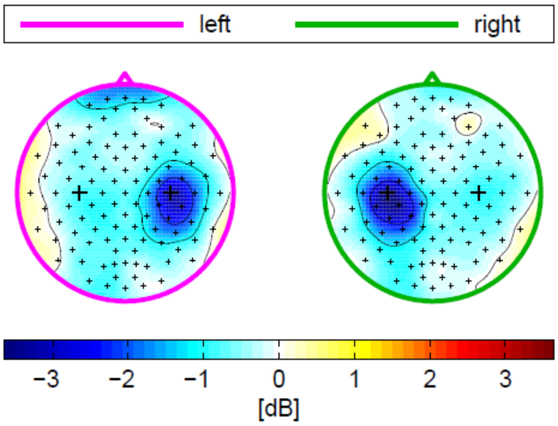

Figure 2: Schematic representation of ERD in a brain. Adaptation from Blankertz et al. [1]. The two bigger pluses indicate the C3 and C4 electrodes needed to detect imagined movement of the left and the right hand. The colours in the image indicate the absolute change in dB of the μ-waves (around $10\,Hz$) between the baseline period (-2000 to $0\,ms$) and the movement period.

the ERDs for both left and right hand movement are visualised, including the location of the C3 and C4 electrodes.

A lot of experiments make use of these three measurable reactions by imagined movement. In imagined movement subjects are asked to imagine movements instead of really performing them. This gives similar reactions in the brain. This experiment uses actual movement instead, because of the ease of performance and detection. For the subjects it is easier to perform movement than to imagine it. Besides that, it is easier to detect real movement, because that gives stronger ERDs.

1.2 Learning

Motivation in learning is an important subject in this experiment, because it aims to test if motivation improves learning. Garris et al. describe in their 2002 paper [4] three main categories in learning, namely: skill-based learning, cognitive learning (consisting of declarative, procedural and strategic learning) and affective learning. Learning how to control a BCI is part of skill-based learning. Gopher, Weil, and Bareket [5] investigated this sort of learning. They trained three groups of flight cadets, two of these groups were trained by playing a game in which they had to control a space ship and had to destroy the enemy, while being chased by several mines. The third group had regular training. They found that the pilots using the game for training perform better in a flight test. Although this was not the first aim of their research, this could denote that the extra motivational aspect that a simulation has compared to regular learning improves performance. Krapp [9] states in his paper about interest, motivation and learning, that learning is indeed influenced by motivational factors. A short description about research on motivation in BCI will follow in section 1.3.

1.2.1 BCI learning

The feedback in a BCI is prone to be slow, because of the time needed to get a sufficiently strong signal to overcome the high noise-to-signal ratio. In a research by Kozuki et al. [8] an experiment was done on the duration between an act and the feedback on that act, and how this influences the learning performance of a subject. Subjects had to push a button on the moment a falling block on the screen touched a target. The feedback on the subject's timing was given at either $80\,ms$ after the act or at $120\,ms$ after the act. It was found that learning was slower with the subjects with later feedback. BCI feedback is usually even slower than the $120\,ms$ and therefore the slow feedback could impede learning. All subjects in this experiment have to deal with this problem, therefore it is not expected to influence the outcome of this experiment.

1.3 Previous work

Some studies have been done on BCIs with virtual reality (VR) feedback. These studies show that the performance of the subjects is better with VR feedback than with regular feedback [10]. Ron-Angevin and Díaz-Estrella [19] argue that feedback needs to be attractive to motivate subjects. To test this, they formed two group of subjects. One group got standard feedback in which they had to extend a bar to the left or to the right, while the other group got the task to move a car from left to right to avoid collisions with obstacles on the road. The error rate of the second group went down during the feedback period, while the error rate of the first group did not. This confirms the idea that attractive feedback can improve performance on BCI and gives the suggestion that motivation improves learning rates. Ron-Angevin and Díaz-Estrella never tested whether the motivation of the group with motivational feedback was bigger than the motivation of the other group and therefore the found effect could also be due to other factors, for example the more familiar environment of the motivational feedback.

The study by Pineda et al. [17] also tries to assess the learning rate with motivational feedback, i.e., a first person shooter, where users could rotate left or right by producing respectively 'low' and 'high' μ-levels. Walking forwards and backwards was controlled by the keyboard. They concluded that the subjects learned very quickly to control the level of their μ-waves. But due to the fact that they did not have a reference group, with less motivational feedback, this does not prove that this kind of feedback is better than more standard feedback.

2 Methods

2.1 Subjects

The subjects in this experiment are divided in two groups, e.g., with boring feedback and with motivational feedback, both consisting of two subjects. The group with boring feedback consisted of two men (age 22 and age 23), from now on referred to as respectively 'Boring 1' and 'Boring 2'. The group with the motivational feedback contained a man (age 22) and a woman (age 21), from now on referred to as respectively 'Motivational 1' and 'Motivational 2'.

2.2 Experimental paradigm

Every subject had to perform five sessions in the experiment. All sessions were the same and the timeline of these sessions is shown in Figure 3. The sessions hold five important stages. First, the subjects are presented with an questionnaire (see section 2.6), then the first offline phase will start. This offline phase consists of 80 trials and the data will be used to train the classifier (training phase). After this offline phase the online phase will begin, consisting of also 80 trials. In this phase the subjects get feedback on their brain activity and the subject learning will occur (testing phase) . Details on the feedback are discussed in section 2.3. The fourth phase is another offline phase (40 trials) in which the subjects have

question.	capfitting	offline 1	online	offline 2	question.
5 min.	15 min.	10 min.	20 min.	5 min.	5 min.

Figure 3: Timeline of a session of the experiment (time indication is an estimate). The first offline phase (offline 1) will consist of 16 sequences of 5 trials. After every sequence the subjects can have a break as long as they like. The online phase also consists of 16 sequences of 5 trials. The last offline phase consists of 8 sequences of five trials. A total session lasts about an hour, depending on the length of the breaks.

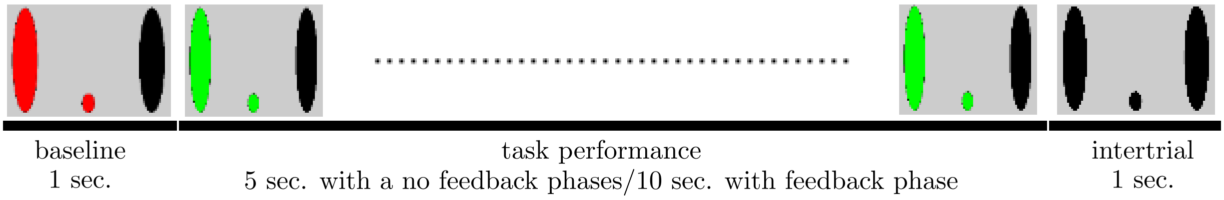

Figure 4: Timeline of one trial, shown with the boring feedback. In the baseline period it is shown which hand movement is up next. Then the task performance period will start in which the hand movement has to be performed. The length of this period depends on the phase of the experiment. In the testing phase the task performance period takes longer. After the task performance the intertrial period starts, in which the subjects have time to blink their eyes. In the motivational feedback there is no visible difference between the intertrial and baseline period.

to perform the task without feedback and their brain activity gets recorded (evaluation phase). Data gathered in this phase is not used in the analysis and merely used to compare with data of the training phase to assess within session learning. After this phase the EEG-recording is over and the subjects will get a final questionnaire before the session ends. All EEG-phases of a session consists of several (80 or 40) trials, the timeline of such a trial is shown in Figure 4.

2.3 Feedback

In the experiment two types of feedback are used, boring and motivational. The boring feedback (see Figure 5) consists of three ellipses, two big ones on both the left and the right side and a small one in the bottom center. The small ellipse in the middle will give the feedback on the brain activity during the testing phase (hence, it moves left when the computer thinks the subject is moving his left hand). The two bigger ellipses function as the targets. When starting a trial, first a baseline appears. In the baseline period the upcoming target and the small ellipse in the middle will turn red. When they both turn green this is a indication the trial starts.

The motivational feedback is built on the source code of the Mario AI Championship 2011 GamePlay track [6] and can be seen in Figure 6. In the motivational feedback Mario will move when movement is executed during the testing phase. Left hand movement will cause Mario to run to the left, while right

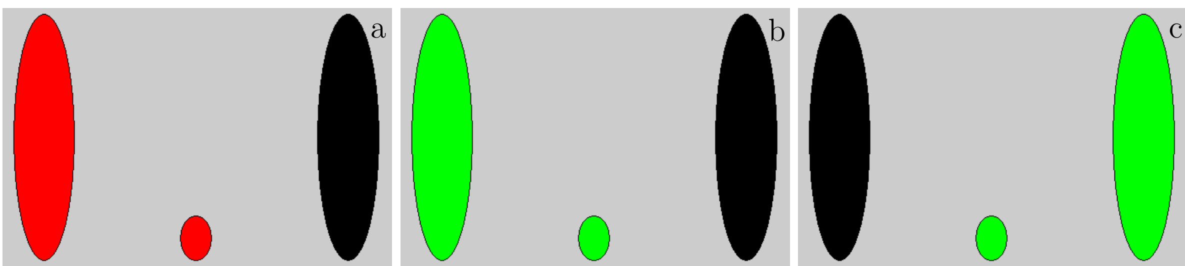

Figure 5: The boring feedback. (a) indicates the baseline for a left trial, i.e., the subject has to move his left hand in the upcoming trial. (b) shows the task execution stimulus for a left trial and (c) shows the task execution stimulus for a right trial.

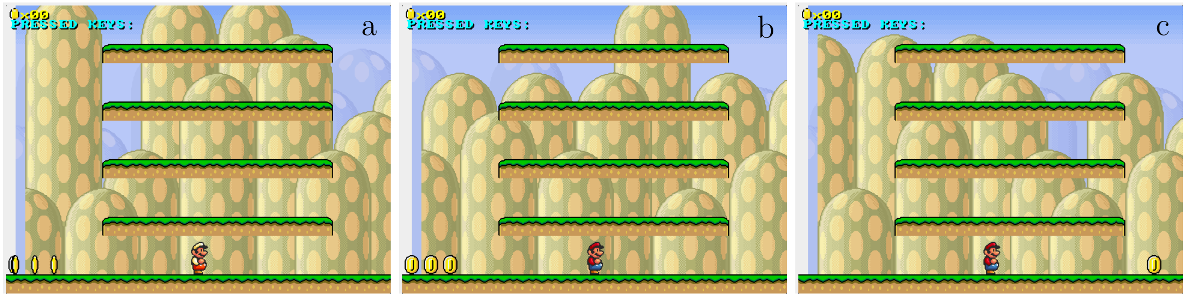

Figure 6: The motivational feedback. (a) indicates the baseline for a left trial, i.e., the subject has to move his left hand in the upcoming trial. (b) shows the task execution stimulus for a left trial and (c) shows the task execution stimulus for a right trial.

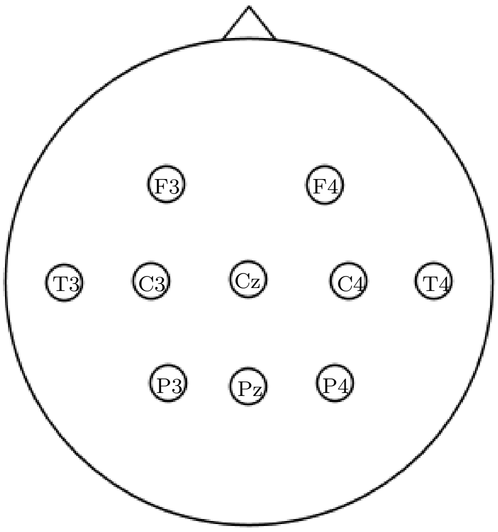

Figure 7: The layout of the electrodes on the scalp of the subjects.

hand movement will cause him to run to the right. The subjects will get the instruction to collect as many coins as possible. The Mario feedback also has a baseline. In the baseline period Mario wears a white cap and shirt with red pants. When he changes colour (red cap and shirt with blue pants) it is an indication that the trial is starting. To give extra motivation the coins that are collected in the current session are counted in the left upper corner.

2.4 Procedure

The experiment has a between subject design. Every subject gets the motivational or the boring feedback, but never both. The assignment to a group is random. All subjects are ignorant on the details of the other group and they are forbidden to talk to each other during the experiment.

2.5 EEG recording

The EEG is recorded with a 10-channel Mobita by TMSi. The Mobita has water-based electrodes. In Figure 7 the distribution of the electrodes over the scalp is shown. The electrodes are placed like this to target the motor area of the subject's brain, therefore the layout includes the target electrodes C3 and C4. The other electrodes surround these electrodes and provide information for artefact cancellation. The ground of the system is located around the left wrist of the subject.

Item	Statement	Factor
1	I look forward to work with the BCI today	I
2	I think I can deal with the difficulties of this task	M
3	Probably the training will not go well today	M
4	I like improving my strategies or trying out new strategies for the training	I
5	I feel under pressure to perform well	F
6	The training is a big challenge for me	C
7	I look forward to start with today's training	I
8	I am very curious how I will perform today	C
9	I dread a little that I can embarrass myself here	F
10	I am fully determined to give my best in the training	C
11	I don't need a reward for the training; I also have fun just like that	I
12	It's embarrassing for me to fail here	F
13	I think that everyone can control his/her brain activity	M
14	I think I won't be able to accomplish the training today	M
15	When I do well in the training today, I will be proud of my achievement	C
16	I am worried when thinking about the training	F
17	I would also train outside the training hours	I
18	The training demands paralyze me	F

Table 1: Questionnaire presented to the subjects before and after every session [13]. The third column contains information which motivational factor the item measures; I, interest; M, mastery confidence; F, incompetence fear; C, challenge. The scores given on item 3 and item 14 should be reversed.

2.6 Questionnaire

All subjects are presented with a questionnaire, two times every session. One at the beginning of the session and one at the end of the session. The questionnaire is designed by Rheinberg et al. [18] and adapted for BCI learning by Nijboer et al. [13]. It is used to measure the motivation of the subjects before and after every session. After every session the subjects are presented with the questionnaire and asked to imagine that they had to take the whole session again. The English version of the questionnaire can be found in Table 1. For this experiment the items labeled with I are of special interest. The subjects themselves are presented with the Dutch version and have to give a value to each question on a five point scale. The exact version of the questionnaire presented to the subjects can be found in Appendix A.

2.7 Data analysis

For analysing the data, only the brain data gathered in the training phase is used. Reason for this is to minimize the influence of the movement on the screen (in the testing phase) and the influence of that days performance, i.e., subject learning and/or tiredness at the end of the session (in the evaluation phase).

2.7.1 Questionnaire analysis

To analyse the questionnaires the items in the questionnaire are grouped by factor (as named in Table 1) and of these groups a mean is taken for every questionnaire. This leaves ten times four values per subject, where each value is between 1 and 5. Now for every session the difference between before and after the sessions is computed (after session−before session) to see the influence of the session on that aspect. The mean of these differences is taken for the subjects with the motivational feedback and for the subjects with the boring feedback to see whether the influence of the feedback differs. The differences are compared instead of the raw values to try to minimize the influence of individuals, that could be very big due to the small sample size.

Subject	Hand	Location	Frequency
Motivational 1	Right	C3	22 Hz
	Left	C4	22 Hz
Motivational 2	Right	C3	20 Hz
	Left	C4	20 Hz
Boring 1	Right	C3	22 Hz
	Left	C4	22 Hz
Boring 2	Right	P3	10 Hz
	Left	P4	10 Hz

Table 2: The locations of the most visible ERDs in the brains of the subjects during hand movement.

2.7.2 Classification rate

As an indirect measure of the learning performance for every session a classifier will be trained, using 10-fold cross-validation, on the data of the training phase of that session. The cross-validated performance of the trained classifier is computed by dividing the correctly classified trials by the amount of trials. This performance is compared over the sessions to see whether the subject gets better in making distinctive brain signals over time.

2.7.3 ERDs

For every session the mean strength (in μV) of the waves from 8 to 30 Hz in the movement phase is computed. By looking at the plotted graphs of these averages, for every subject an electrode-frequency combination was chosen by eye for left hand movement and for right hand movement. This combination indicates the place and frequency in the brain where the ERDs are the most visible. For two subjects there were no ERDs visible in the training phase. For these subjects also the data gathered in the testing and observe phases was considered to indicate the location of their ERDs. The locations and frequencies used per subject can be found in Table 2.

The strength of the ERD caused by right hand movement are computed by taking the average strength of the given frequency in the given location during movement of the left and the right hand. After that, the difference between these two strengths is computed and then divided by the sum of those two strengths ((left hand−right hand)/(left hand+right hand)). For left hand movement the method is the same, only the subtraction is the other way around ((right hand−left hand)/(left hand+right hand)). These two values are averaged to get one value expressing ERD depth for every session.

3 Results

3.1 Questionnaire

The most important factor tested in the questionnaire is interest. In Figure 8 the differences in interest between the start and end of every session are shown. It is visible that on average the group with the boring feedback loses more interest during the session. It is also interesting to point out that there is an increase in loss of interest in this group. In the first session they gained interest, but in the last session they lose a lot of interest. With the group with motivational feedback this increase in loss seems not the be present, this group stays more or less on the same difference level. An important thing to notice is that the group with motivational feedback has on average a higher mean in interest before the session (motivational feedback group: 3.84, boring feedback group: 3.72), therefore the bigger loss of the group with boring feedback cannot be due to the fact that they started at a higher level and can therefore lose more.

The other factors tested in the questionnaire are less important for the research, but gave some interesting results. The factor incompetence fear for example. Overall the group with motivational feedback started the session with a lower incompetence fear than the group with boring feedback (motivational feedback group: 1.80, boring feedback group: 1.98) and in addition to this they also lost more fear during the sessions (see Figure 9a). So besides to being more interesting it seems that the motivational feedback takes away fear.

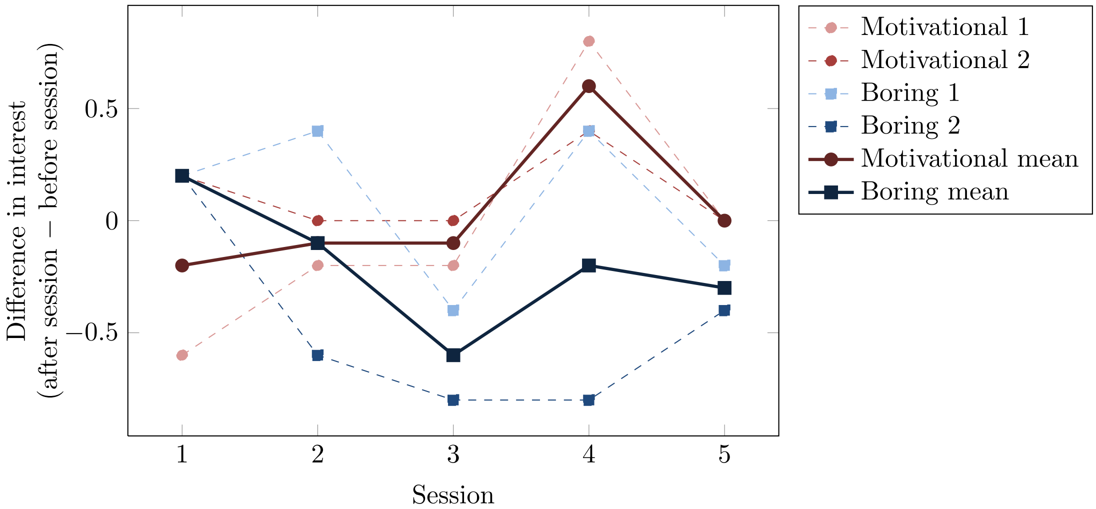

Figure 8: The difference of interest for all subjects between before and after every session and the mean of this value for both groups of subjects. Zero means that they had the same interest before and after that session. Below zero means they lost interest, above zero means they gained interest during a single session.

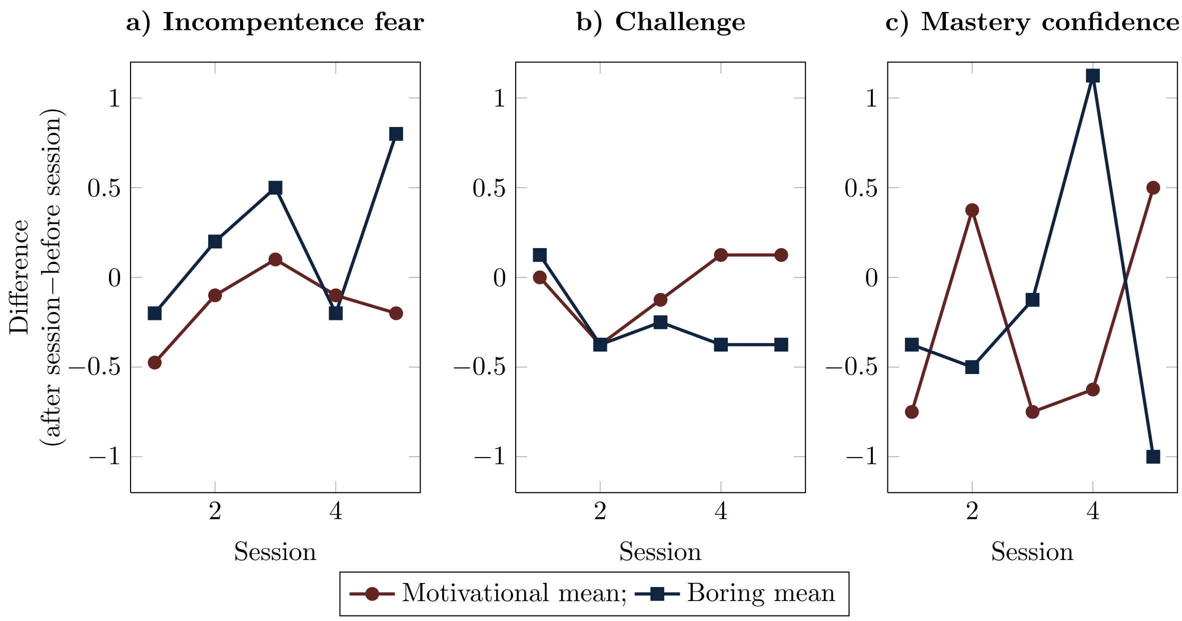

Figure 9: The average difference of the factors incompetence fear, challenge and mastery confidence for both groups of subjects between before and after the session. A negative number means that this factor decreased during the session. A positive number means that it increased.

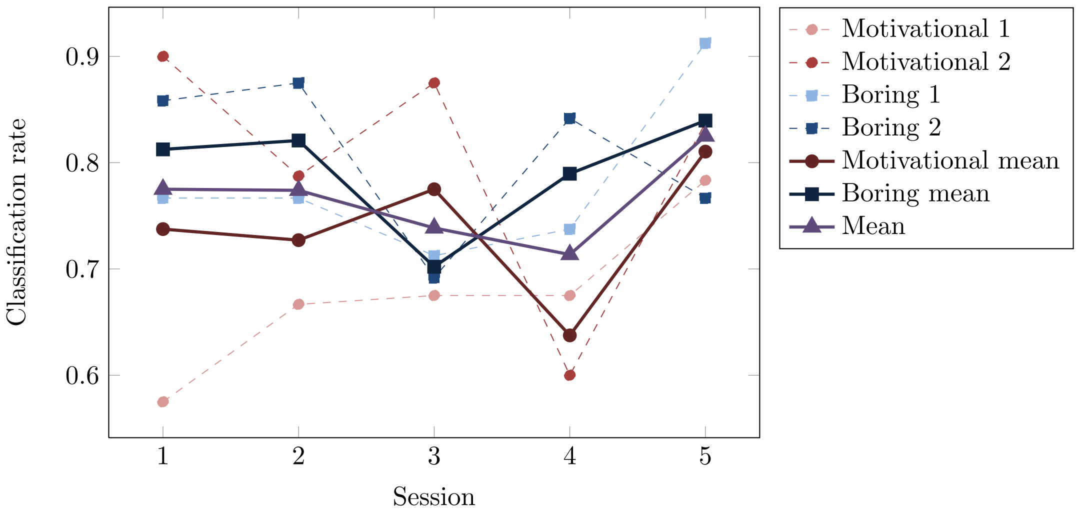

Figure 10: The classification rate of the classifier on the trainings samples per session for every subject and the mean of this value for both groups of subjects and the mean for all subjects.

In Figure 9b you can also see that the difference in challenge is most of the time more positive for the motivational feedback than for the boring feedback. On the other side it is interesting to note that the challenge value before the sessions goes up with boring feedback and down with motivational feedback, while after the session it is the other way around. These differences are very small, so it is not said that these effects are significant.

The last factor tested with the questionnaire is mastery confidence. This factor is the hardest to interpret, because it is most dependent on the performance of a single day. These performances are not stable, and therefore the mastery confidence is also unstable. This makes it hard to interpret Figure 9c.

3.2 Classification rate

In Figure 10 the classification rates for the different subjects are plotted. In this graph it is visible that the classification rates are very unpredictable and they differ a lot over time. In session one there is a difference between the group with the motivational feedback and the group with the boring feedback and in the last session this difference shrunk. This could be an indication that the motivational feedback group learned more, but due to the very different results in the fourth session, this is a very weak argument.

When you look at the change in classification rate with respect to the first session, plotted in Figure 11, you see very clearly that the subject Motivational 1 improved his classification rate the most. However, he had the lowest classification rate in the first session and therefore the most room for growth. Another noticeable thing about this subject is his stable growth. All other subjects have at least one fall back, while this subject stays stable or improves every session.

It is also good to notice that the subjects with the higher classification rate in the first session (Motivational 2, Boring 2) did not learn. This can be an indication that there is an upper boundary to which a subject can learn, this is possibly due to the delayed and noisy feedback.

When you look at the averages plotted in this graph you see that there is not a real difference in learning between the group with motivational feedback and the group with boring feedback, because the classification rate is too dependent on the day. Looking at the overall mean, you see an increase of the average classification rate, especially at the end. Comparing the first session classification rate with the the last session classification rate in a one-tailed, paired t-test a p-value of $p \approx 0.276$ was found. This value is too high to say that there is a statistical difference between the first and the last session, but this could be due to the small sample size. However, the reasonably low value is suggestive that some learning happened during the sessions.

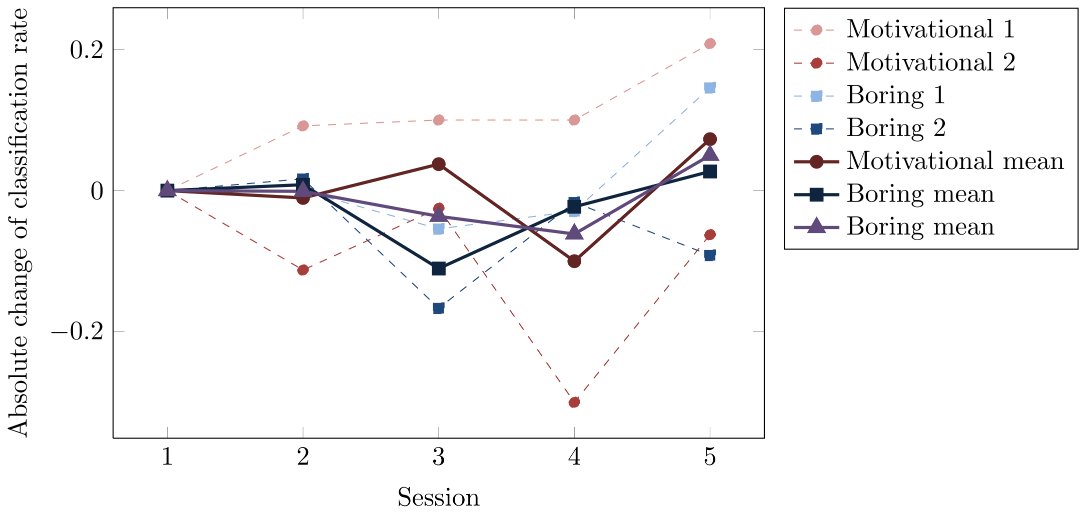

Figure 11: The absolute change of classification rate with respect to that subjects first session and the mean of this absolute change for both groups of subjects and the mean for all subjects.

3.3 ERDs

In Figure 12 the brain signals of Boring 1 are shown. This is the subject with the most obvious growth in brain signals. The red lines indicate the place where the samples are taken to compute the ERD. The learning is most visible in the C3 electrode in the left side of the brain, which should show an ERD for right hand movement. In the first session the lines of left and right hand movement are almost the same, so there is no effect of hand movement on the brain signals. However, in the last session there is a real difference between left and right hand movement in the presence of the frequencies from 20 to 24 Hz. For right hand movement is the presence of these frequencies a lot lower (for the measuring point of 22 Hz the difference is $0.303\,\mu V$). This growth indicates that this subject learned how to produce ERDs in the left side of his brain.

In Figure 13a this is also visible. This figure shows the computed ERDs for the trials with right hand movement. It is visible that the ERD of Boring 1 is the only signal that is growing every session, even though the signal of Boring 2 is also mainly improving. The two subjects with the motivational feedback do not produce any visible ERDs for their right hand movement in the training sessions. Most of the time the computation gives negative values. This is not as expected, but what is as expected is that they do not improve this signal over time, because they do not start with anything to learn from. It is important to note that especially Motivational 2 had high classification rates, so the classifier output does not appear to be directly related to ERDs which were not visible in the data.

Also the ERDs that should have been produced by left hand movement are not really apparent in this subject. In Figure 13b the ERDs of left hand movement are shown. In session three she has a really big ERD in her right hemisphere. Whether this is a classic movement induced ERD is doubtful, because she had the same pattern in the left hemisphere (visible in Figure 13a by the very low point in session 3). The other subjects also did not seem to learn producing stable ERDs in the right hemisphere. The ERDs in this hemisphere seem to be very dependent on the moment and therefore it can not be said that one (or more) of the subjects has a mainly rising line.

In Figure 14 the ERDs of left hand movement and right hand movement are averaged for all subjects, and for the mean of both groups. Here you see that both subjects in the motivational feedback group did not produce visible ERDs in the training sessions. The subjects with the boring feedback did produce some visible ERDs already in the first session. In Figure 15 you see for all subjects how the ERDs changed with respect to the ERDs in their first session. The means for both groups show that the group with the boring feedback shows stronger growth in their ERDs, than the groups with the motivational feedback, probably because the subjects with the motivational feedback did not produce strong enough ERDs to learn from in early sessions. Both subjects with boring feedback did some learning, although these results are not stable.

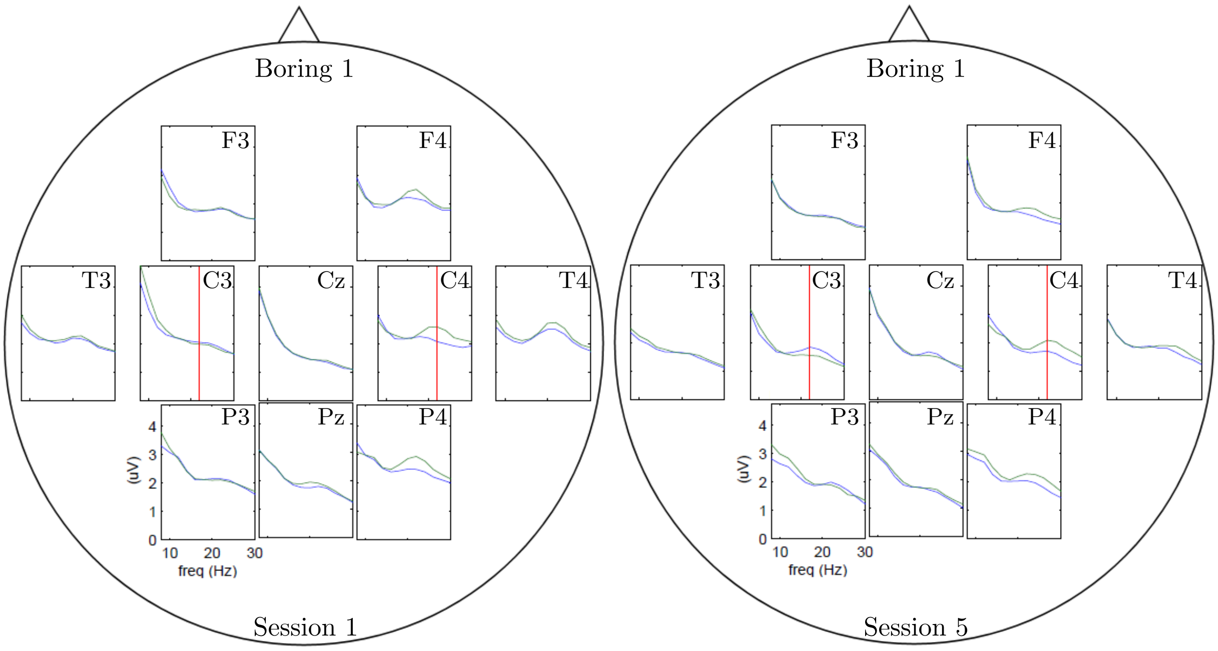

Figure 12: Brain signals of Boring 1 in the first and in the last session. The blue line shows the signals for left hand movement, the green line for right hand movement. The red lines show at which point the samples for the ERD are taken.

Looking at the graphs, especially the third session is notable, both in classification rate and ERDs. The performance of the subjects in this session is lower than in other sessions. Looking at the questionnaire, it shows that especially the subjects with the boring feedback lost a lot of interest during the session that day (loss of 0.6, while the average loss for subjects with boring feedback during session is 0.2). This does not show directly for the group with motivational feedback, but could still be the reason for the low performance. Probably, the middle session is least motivating, because in the first session everything is new and in the last session the subjects are happy to be done.

4 Discussion

Due to the small sample size, none of the results are conclusive and they can only give indications and grounded reasons for future research.

4.1 Feedback

First important thing to notice is the results of the questionnaire. These results give a very strong indication that the motivational feedback is more motivational than the boring feedback. The group with the motivational feedback loses less interest during sessions, which shows that they are more motivated by the sessions. This is an important fact, because BCI training is often boring and takes a long time. If users are eager to learn, it is always a gain, because users will be less repelled by the long training periods. Therefore, researchers wanting to let subjects learn to alter their brain signals, should look at the possibility of altering their feedback to make it more motivational. This can lead to subjects who are willing to come back more often and give their best during training.

4.2 Learning

This research shows that movement based BCI is learnable at least for some subjects. Two subjects improved their classification rate (Motivational 1, Boring 1) and at least one subject learned how to produce stronger ERDs in one side of his brain (Boring 1). To get more learning effect it might be a good idea to have more sessions per subject.

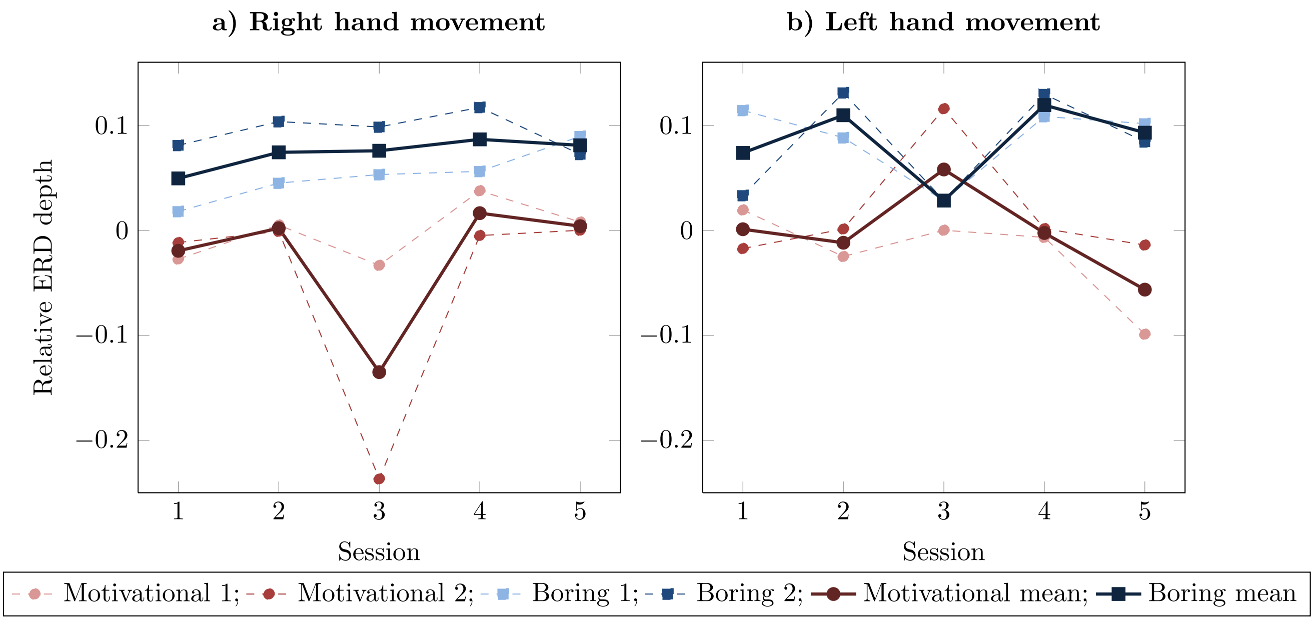

Figure 13: The average ERDs measured at left hand movement (a) and right hand movement (b) for every subject and the means for both groups of subjects

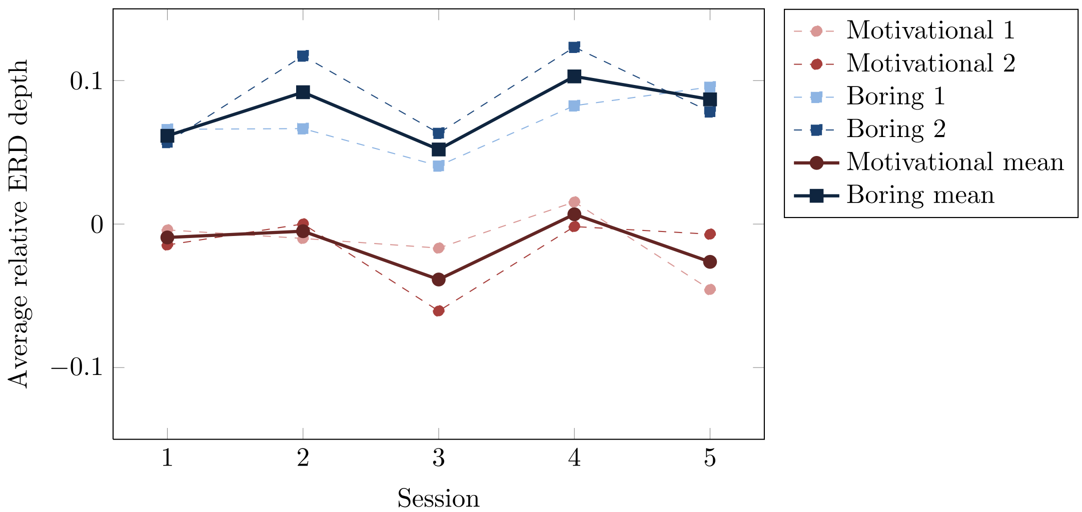

Figure 14: The ERD depth (mean of left hand and right hand ERD) for all individual subjects and the mean for both groups of subjects.

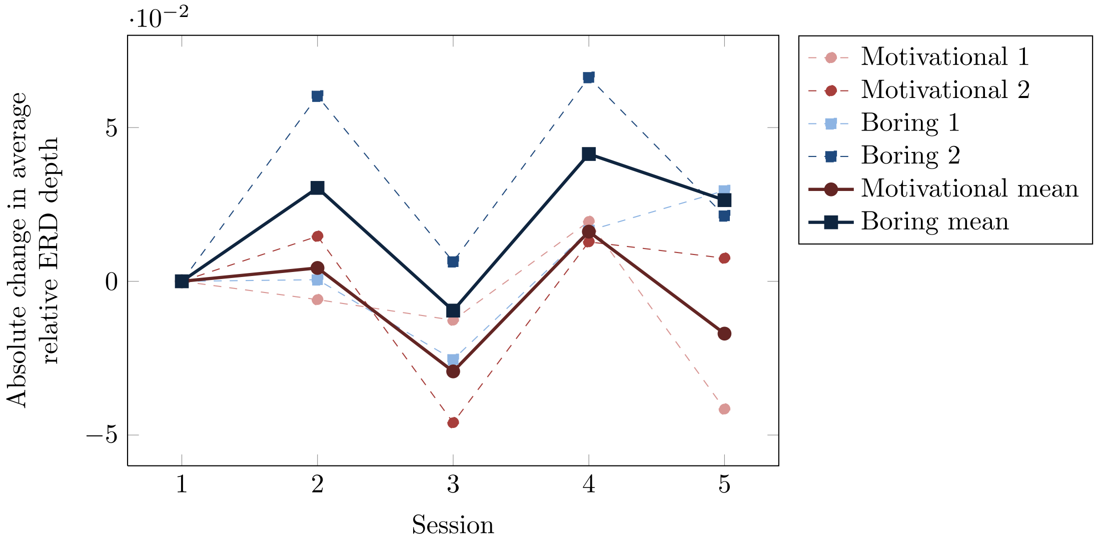

Figure 15: The change of the ERD depth (mean of left and right hand ERD) over the sessions with respect to the first session for every subjects and the mean for both groups of subjects.

There seems to be a difference in motivation between the two groups, but this does not directly reflect on the learning performance of the subjects. There is not a clear difference between the groups, when it comes to the speed of their learning. This is not as hypothesised before starting with the research. There are two possible reasons for this. First, it is possible that the hypothesis is wrong and that there is no effect of motivation on the speed in which someone can learn using a BCI. A second possible reason is the small sample size. With only two subjects in every group the results are very prone to individual factors. This last reason is really probable, because there is some research indicating that motivation can improve learning. To confirm this second reason more research has to be done.

4.3 Future research

The most important next step in this research is to do a similar experiment with more subjects. By doing that, it can be confirmed that the counter-intuitive results are due to the small sample size. If these results turn out to be due to this small sample size, such a follow-up study can prove that motivational feedback can improve learning.

Another point is making the feedback even more motivational. Except from the looks of the different feedbacks, they are very similar, this was needed to rule out that the improved learning was due to something else than motivation as much as possible. If motivational feedback finds its way into new research it could be better to use even more motivational feedback, probably by making real game out of it. This could improve motivation even more and therefore will give subjects more reason to give their best in training.

Furthermore, it could be an idea to switch feedback over the sessions. This might overcome the bad performance during the middle session. By occasionally changing feedback it might keep the subjects motivated over all sessions, which could result in improvement in every session. When doing this it has to be made sure that, besides the feedback, the task is the same for every sort of feedback.

A last interesting topic for future research concerns finding out what aspects a feedback should have in order to motivate people. In this research a few aspects that could be reason for the motivation are for example the looks of the feedback, the familiarity with the Mario game and the counter that keeps track of the number of coins already gathered. Some aspects that could be added to make it more motivational are for example sounds or a game with a story mode. It could be interesting to find out what is needed to make a feedback as motivational as possible.

5 Conclusion

This research showed that it is possible to motivate subjects more by using different feedback and that some subjects were able to learn how to control a movement based BCI. The actual research question (i.e. 'Does motivation improve performance in learning how to use a movement based brain computer interface?') of this experiment remains unanswered. Due to the small sample size it is not conclusive whether motivation increases learning rate and even a strong indication is not given. This does not necessarily mean that motivation does not improve learning rate, but more research is needed to find out the answer to the research question.

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Appendix

A Questionnaire in Dutch

Vragenlijst BCI

Volgnummer: ________

	Oneens ←			→ Eens
1. Ik kijk er naar uit om met de BCI te werken vandaag	☐ ☐ ☐ ☐ ☐
2. Ik denk dat ik om kan gaan met de moeilijkheden van de taak	☐ ☐ ☐ ☐ ☐
3. Waarschijnlijk gaat de training vandaag niet zo goed	☐ ☐ ☐ ☐ ☐
4. Ik hou ervan mijn strategieën te verbeteren of nieuwe strategieën te proberen tijdens de training	☐ ☐ ☐ ☐ ☐
5. Ik voel druk om goed te presteren	☐ ☐ ☐ ☐ ☐
6. De training is een grote uitdaging voor mij	☐ ☐ ☐ ☐ ☐
7. Ik kijk er naar uit om met de training van vandaag te beginnen	☐ ☐ ☐ ☐ ☐
8. Ik ben erg nieuwsgierig naar hoe ik vandaag zal presteren	☐ ☐ ☐ ☐ ☐
9. Ik vrees een beetje dat ik mezelf voor schut ga zetten hier	☐ ☐ ☐ ☐ ☐
10. Ik ben vastbesloten om alles te geven tijdens de training	☐ ☐ ☐ ☐ ☐
11. Ik hoef geen beloning voor de training; ik heb zo ook plezier	☐ ☐ ☐ ☐ ☐
12. Ik schaam me als ik hier faal	☐ ☐ ☐ ☐ ☐
13. Ik denk dat iedereen zijn/haar brein activiteit kan controleren	☐ ☐ ☐ ☐ ☐
14. Ik denk dat ik niet in staat ben de training van vandaag te volbrengen	☐ ☐ ☐ ☐ ☐
15. Als ik het goed doe op de training vandaag, ben ik trots op mijn prestatie	☐ ☐ ☐ ☐ ☐
16. Ik maak me zorgen als ik aan de training denk	☐ ☐ ☐ ☐ ☐
17. Ik zou ook buiten de train uren gaan trainen, als ik de mogelijkheid had	☐ ☐ ☐ ☐ ☐
18. De eisen bij de training overwelmen me	☐ ☐ ☐ ☐ ☐