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# The Influence of Motivation when the Task gets Harder: Visual versus Auditory P300 Brain-Computer Interface Performance

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**Abstract**

This study investigated the influence of motivation on Brain-Computer Interface (BCI) performance with increased difficulty of the BCI task by changing the sensory modality of the input stimulation from visual to auditory. We found increased brain activation in response to the stimulation during the auditory task when participants were highly motivated as compared to being moderately motivated.

## 1 Introduction

Motivation was shown to have an influence on Brain-Computer Interface performance (e.g. Kleih et al., 2010; Hammer et al., 2012). When using the event-related potential P300 as BCI input signal, it was hypothesized that motivation might increase attentional resource allocation and thereby brain activation and classification accuracy (Kleih et al., 2010). This hypothesis also suggests motivation to be more influential when the task gets more demanding. The allocation of additional attentional resources to the stimulation alone might increase brain activation and thereby balance the effect of less detectable brain signals due to increased complexity of the task. However, this assumption has never been systematically investigated. In the here presented study we systematically increased participants' motivation by monetary reward and compared performance in the visual and auditory sensory input channel with the auditory modality representing the more difficult task. We hypothesized an increase of motivation by monetary reward (H1), an increase of brain activation (P300 amplitude) as a function of motivation and this effect to be more distinct in the auditory as compared to the visual modality (H2) and higher performance when being motivated (H3).

## 2 Methods

### 2.1 Participants

We recruited N=14 students with an average age of 27.00 years (*SD* = 7.30, range 19-38). Three males participated in the study and none of the participants reported a history of neurological or psychiatric disorder. Participants were paid 8 € per hour and all were naïve to BCI training prior to participation. Participants gave informed consent to the study, which had been reviewed and approved by the Ethical Review Board of the Medical Faculty, University of Tübingen.

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## 2.2 Procedure and Stimulation Parameters

After calibration, participants had to spell the words 'BRAIN' and 'POWER' with an auditory and a visual P300 BCI under three different reward conditions. In condition "0ct" they received no reward for correctly spelled letters, in condition "5ct" they received 0.05 € for every correctly spelled letter (maximum win: 0.50 €) and in condition "100ct" they received 1 € for each correct letter (maximum win: 10.00 €). We used these rewards as we were interested whether an additional reward would already increase motivation (0.05 €) or whether motivation can only be increased by a relatively high and salient reward (1€). In the visual condition, ten sequences were used, thus each individual character was flashed 20 times. Each stimulus, row or column, flashed for 312.5 ms. Afterwards, the screen was static for another 312.5 ms. Thus, the presentation of the rows and of the columns both had a duration of 31.5 s, which means that one character could be selected every 62.5 s. An interval of 5.625 s was provided before each sequence such that participants could locate the next character in the matrix. For the auditory modality, the auditory speller introduced by Furdea and colleagues (2009) was used. In that auditory version of the P300-speller, letters were represented by a combination of two numbers which indicated its matrix location. Each character therefore could be defined by the coordinates of these number codes. Auditory stimuli consisted of computer-generated numbers spoken by a male voice. To select a particular target character, the participant had to attend to two target stimuli representing the coordinates of the character in the matrix while within one trial only either the number representing the row or the column was presented. Participants viewed the same matrix as in the visual speller to support finding the coordinates of the character-to-select.

All conditions (reward and modality) were counterbalanced. Participants were told before every condition how much money they could earn for every letter correctly spelled and the maximum win they could obtain. The experimenter scored every accurate letter, but the participant did not receive feedback during the run to prevent any effect of success on motivation. Immediately after every condition, motivation was assessed using a visual analogue scale (VAS) ranging from 0 (not motivated at all) to 10 (very high motivation). Only after finishing all six conditions, participants received feedback of their performance and the amount of money they had earned.

## 2.3 Data acquisition and analysis

Stimulus presentation and data collection were controlled by BCI2000 software (Schalk et al., 2004). The EEG was recorded using a tin electrode cap (Electro-Cap International, Inc., Eaton, OH) with 16 channels. Electrode locations were F3, Fz, F4, T7, C3, Cz, C4, T8, CP3, CP4, P3, Pz, P4, PO7, Oz, PO8 based on the modified 10-20 system. Each electrode was referenced to the right and grounded to the left mastoid. The EEG was amplified using a 16-channel g.USBamp (Guger Technologies, Austria), sampled at 256 Hz, and bandpass filtered between 0.01 – 30 Hz. Fifty Hz noise was filtered using a notch filter implemented in the BCI2000. Data processing, storage and stimulus presentation was controlled with DELL laptop (Intel Core 2 Duo T5550 1.83 GHz, GB DDR2, Windows XP). Stepwise linear discriminant analysis (SWLDA) was used for classifier weights generation after the initial calibration sessions. The EEG data were corrected for artifacts and baseline (-100 to 0 ms) using Brain Vision Analyzer 2® (Brain Products Germany). The P300 was defined as the maximum positive peak occurring between 200 and 700 ms after stimulus onset and was chosen by semiautomatic global peak detection. For statistical analysis IBM SPSS® 20 was used. The level of significance was set to $\alpha = .05$.

# 3 Results

The first hypothesis that monetary reward would increase participants' motivation was tested with repeated measures analysis of variance (ANOVA) with the factors *modality* (visual and auditory) and *reward* (0ct, 5ct, 100ct) and the dependent variable VAS motivation. We found a main effect for *reward* ($F_{(2,28)}$= 4.94; $p$<.05). Within-subjects contrasts revealed a significant motivation increase between 5ct and 100ct ($F_{(1,14)}$ = 5.34, $p$ <.05). Neither a main effect for modality nor an interaction effect was found.

H2 stated that increased motivation would lead to increased brain activation as reflected in the P300 amplitude. When calculating repeated measures ANOVA with the factors *modality* and *reward* and the dependent variable *P300 amplitude*, we found P300 amplitudes in the visual modality to be significantly higher than the P300 amplitudes in the auditory modality ($F_{(2,28)}$ = 72.48, $p$ < 0.01). However, there was no effect of monetary reward on the P300 amplitude ($F_{(2,28)}$ = 0.09; $p$ = 0.92) nor an interaction ($F_{(2,28)}$ = 1.48; $p$ = 0.25). When comparing brain activation in the auditory modality (see figure 1) between the 5ct and the 100ct conditions, it is apparent that there is higher activation in the 100ct reward condition even though no clear ERP peak is detectable. Therefore, areas under the curve (AUC) in the different auditory conditions were compared. The measure of AUC represents the integral under the curve in a defined time interval. With AUC the distance of each data point from zero is ignored while calculating the integral with reference to the first value of the interval (Pruessner et al., 2003). We compared AUC values with repeated measures ANOVA for two target *electrodes* (Cz, Pz, see figure 1) and the *reward* conditions (0, 5, 100 Cent). A trend towards a main effect of *reward* condition was found ($F_{(2,22)}$ = 3.21, $p$ = .06). Within-subjects contrasts revealed a significant difference between reward conditions 5ct and 100ct ($F_{(1,11)}$ = 4.99, $p$ < .05) but not between 0ct and 5ct conditions ($F_{(1,11)}$ = .09, $p$ = .77). No main effect of *electrode* ($F_{(1,11)}$ = .21, $p$ = .65) was found.

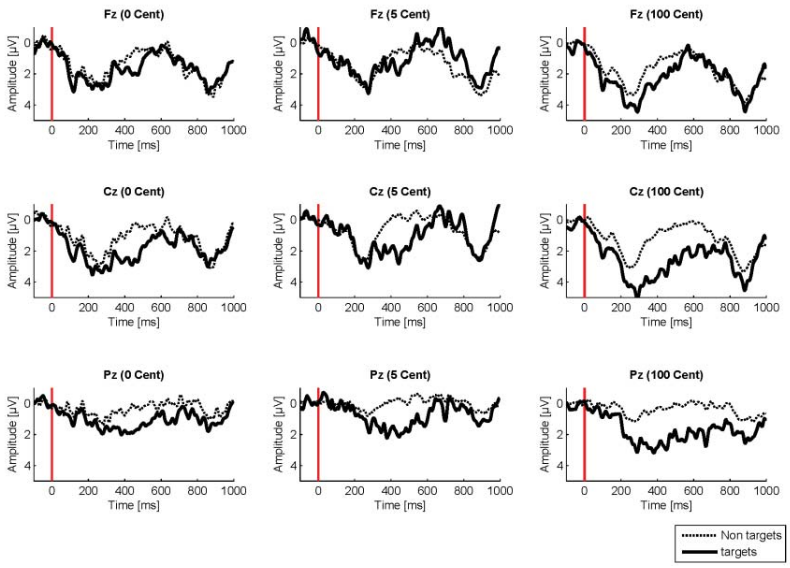


**Figure 1:** Brain activation 1 s after stimulus onset in the auditory modality at Fz, Cz and Pz for the motivation conditions 0ct, 5ct and 100 ct reward.

Concerning performance (H3), participants were more successful in the visual ($M$ = 95.12% accuracy, $SD$ = 9.60) as compared to the auditory task ($M$ = 44.88% accuracy, $SD$ = 30.66, $F_{(1,14)}$ = 65.91, $p$ < .001). Motivation did not increase accuracy ($F_{(2,28)}$ = 2.03, $p$ = .15) and no interaction effect was found between modality and monetary reward ($F_{(2,28)}$ = .87, $p$ = .43).

# 4 Discussion

We showed that motivation to perform a BCI task could be successfully manipulated with monetary reward. Compared to the study from Kleih and colleagues (2010), we used higher reward for a correct selection (0.50 € in Kleih et al., 2010 versus 1 € in this study) and the intervals between the monetary rewards were unequal (0, 5, 100 € Cent). We assume this caused a more salient perception of the reward value as compared to the study by Kleih and colleagues (2010). Our hypothesis of motivation to increase and thereby balance potentially reduced brain activation in more difficult tasks was supported by the here presented data. We found an increase of brain activation as measured with the area under the curve in the auditory task in the 5ct and the 100ct motivation condition as compared to the 0ct motivation condition. This result suggests the influence of psychological variables, such as motivation, to be higher when tasks become more challenging while at the same time motivation seems to increase only with the highest possible reward condition. However, the results should be interpreted with caution as spelling accuracy was not influenced by motivation and in the visual version of the P300-speller it was almost twice as high as compared to the auditory. Furdea and colleagues (2009) also found a clear advantage of the visual over the auditory modality. However, in their study no differences in P300 amplitudes were found while in our study we found significantly lower P300 amplitudes in the auditory condition compared to the visual one. This was probably caused by our decision to use less sequences than Furdea and colleagues (2009) as we wanted to avoid a ceiling effect in performances especially in the visual P300 speller (Furdea et al., 2009; Kleih et al., 2010). In conclusion, we found that motivation can be manipulated by monetary reward in a BCI task, that motivation does influence brain activation when the task is demanding and that this brain activation increase does not affect BCI performance in terms of accuracy, i.e. correctly selected letters.

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