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THE EFFECT OF PERFORMANCE EXPECTANCY AND ACHIEVEMENT MOTIVE IN A P300 BASED BRAIN-COMPUTER INTERFACE

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ABSTRACT: We investigated the effect of performance expectancy and achievement motive on P300 BCI performance. Thirty-eight participants were separated in two groups according to their achievement motive and classified as either avoiding failure (AF) or approaching success (AS). Participants were presented with three different matrices in the colors red, green and blue and were told that spelling would be difficult, moderately difficult or easy depending on the color. We hypothesized AS participants to perform best and to show highest P300 amplitudes in a spelling condition perceived to be moderately difficult. AF participants were hypothesized to perform worst and to show lowest P300 amplitudes in the spelling condition perceived to be moderately difficult. Participants spelled six five-letter words in each perceived difficulty condition. We found highest P300 amplitudes in the easy condition irrespective of achievement motive; however, no differences concerning performance in percent correct responses. Even though we could not find an effect of performance expectancy on the behavioral level, we did show that performance expectancy does affect BCI performance on the physiological level.

INTRODUCTION

Motivation. Heckhausen and Heckhausen [1] describe motivation as a collective term for psychological processes that are necessary to choose a certain behavior and manage the required effort for pursuing that behavior after evaluation of expected results. Motivation, more precisely, summarizes processes such as stringency, beginning and finalizing a behavior, returning to a behavior after an interruption, possible conflict between several behavioral goals und the solution of this conflict. Heckhausen subsumed the cognitive processes related to motivation in his Cognitive Model of Motivation [2]. Based on this model, a person's motivation could be estimated (fig. 1). Four different components contributing to motivational force were distinguished: 1.) perceived situation, 2.) action, 3.) intended goal or outcome and 4.) consequences (see fig. 1). Transferred to a BCI context, the perceived situation would be the possibility to use a BCI system. The action to be taken would be the willingness to use the system and therefore, some kind of mental effort, such as focusing attention in a BCI system based on evoked potentials. The intended goal would be the successful selection of letters in a P300 BCI for spelling or, more general, BCI control. If successful, that would lead to the anticipated consequence of successful interaction with the environment. A person's subjective expectancy of a behavior leading to a certain outcome or consequences contributes to motivational force.

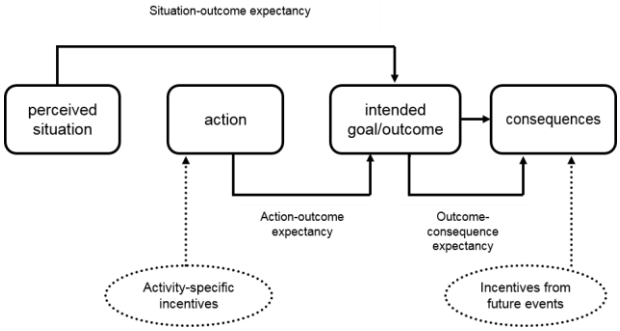

Figure 1: The Cognitive Model of Motivation [2].

In case, a BCI system would be usable but the user does not expect to be able to control the BCI system, motivational force would be low. Expectancies that influence the interaction between the mentioned components were classified by Heckhausen as follows: 1.) situation-outcome expectancy, 2.) action-outcome expectancy and 3.) outcome-consequence expectancy. Situation-outcome expectancy (SOE) describes the expectancy that an outcome will occur, even without taking any kind of action. In case such expectancy is high without changing behavior, motivation for action taking would be low. In a BCI context of course, without the user taking action, no BCI control will be possible, therefore the user can only develop action-outcome expectancy (AOE) by engaging in the BCI task. The user should expect a certain action, in this case focusing attention on the stimulation to influence the outcome, which would be P300 based spelling. Outcome-consequence expectancy (OCE) describes the expectancy that a desired consequence will follow the outcome. In a BCI context, the user might anticipate the desirable consequence of being able to interact with the environment based on his or her brain activity. Heckhausen also postulated two kinds of incentives that influence motivation: 1.) action specific incentives and 2.) incentives from future events. In a BCI context, action specific incentives might be interest in the

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functionality of a BCI system and having the possibility to control such a system. In addition, of course, there are incentives from BCI performance as in a P300 speller, feedback directly informs the user about his or her performance level. Incentives from future events might be improvements in BCI use over time or achievement of goals based on BCI use, such as painting pictures [3]. Naturally, incentives from future events are more relevant in case BCI end-users with disease are involved as compared to healthy students who might never use a BCI system again after participation in one experiment. We cannot fully transfer Heckhausen's assumptions [2] postulated for non-BCI situations to a BCI context. When participating in a BCI study, some students volunteered without knowing anything about a BCI system. There is no deliberate choice to engage in BCI use. There even might be a deliberate choice to collect credit points by participation, such that there is a motivational goal underlying BCI use that is completely independent from BCI spelling. Thus, theoretical components such as situation-outcome expectancy might change during participation ("I volunteer for credit points" versus "I am really getting interested and believe that I can control this device by focusing attention"). Nonetheless, BCI use will most likely touch a persons' performance motivation specifically during P300 spelling, as it becomes immediately clear whether a person would be able to communicate via the BCI. Therefore, an inherent, cross-situational achievement motive might be triggered as a trait variable of motivation and should be addressed in this context.

Achievement motivation. In his theory of achievement motivation Atkinson postulated a person inherent achievement motive to influence motivation in achievement situations [4]. This motive consists of two specifications that might differ in every person and together add up to a person's individual tendency to undertake an achievement-oriented activity. One specification is the motive to approach to success, which describes a person's need to succeed or tendency to expect success. The other specification is the motive to avoid failure, which represents a person's fear of failure. Atkinson postulated persons with high tendency to approach success to prefer performance situations of medium difficulty. In such situations, the likelihood of success seems highest and chances to succeed are most promising. People with a high tendency to avoid failure were hypothesized to prefer situations of low or very high difficulty. Very easy tasks might be easily manageable; therefore, fear of failure would be low. Very difficult tasks might be judged as so difficult that failure would not result in a threat towards a person's abilities. Tasks of moderate difficulty are potentially threatening as in these tasks ability (and inability) might become obvious.

As postulated in the triarchic model of P300 amplitude [5], P300 amplitude varies depending on the value the stimulation represents for the BCI end-user. Based on the individual achievement motive as expressed by the motive to approach success or to avoid failure, the P300 speller stimulation might be perceived of different value when a BCI task is perceived to be easy, moderate or difficult which in turn will influence situation-outcome expectancy, action-outcome expectancy and outcome-consequence expectancy.

Studies on motivation in a BCI context. To our knowledge, there are no BCI studies yet, in which the influence of trait variables of motivation were investigated in the context of BCI use. Motivation was assessed as a state variable and it was shown that healthy participants usually highly motivated in a P300 spelling task [6]. In several studies [7, 8, 9] motivation was assessed using the Questionnaire for the assessment of Current Motivation during BCI use (QCM-BCI, [10]). The QCM-BCI is a BCI adapted version of the original QCM [11] to account for using a BCI instead of making predictions about performance and success in cognitive learning tasks. The QCM-BCI comprises 18 items divided into four subscales *incompetence fear*, *mastery confidence*, *interest* and *challenge*. Incompetence fear correlated negatively with BCI performance in healthy participants [12]. In stroke patients, mastery confidence correlated positively with BCI performance and negatively with spelling speed [12].

Therefore, state variables of motivation, such as mastery confidence and incompetence fear seem to influence BCI performance. It remains unclear whether trait variables of motivation such as the motive to approach success or the motive to avoid failure [13] also influence BCI performance. As P300 based spelling can be perceived as a performance task, trait variables might be activated. Dependent on the individual expression of the mentioned motives, P300 amplitudes and BCI performances might vary with perceived task difficulty. We hypothesized participants with a high motive to approach success to perform best and to show highest P300 amplitudes in a P300 spelling paradigm perceived to be moderately difficult. Participants with a high motive to avoid failure should perform worst in a task perceived to be moderately difficult and to show lowest P300 amplitude in this condition.

MATERIALS AND METHODS

Sample. Thirty-eight healthy students participated in this study, n=27 were female. Mean age was 22 (SD=3.00). All participants were naïve to BCI use and gave written informed consent to the study. The study was approved by the Ethical Review Board of the Medical Faculty, University of Tübingen, Germany.

Procedure. To measure the motive to approach success and the motive to avoid failure, the Multi-Motiv-Gitter [MMG, 14] was used. MMG test criteria

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are satisfactory with a re-test reliability between .88 and .92. The MMG is a semi-projective questionnaire, in which a participant judges a situation shown as a drawing. Several statements to that drawing are offered and the subjectively fitting ones are to be selected. Exemplary statements are: "you can lose your reputation here" or "you can impress with performance". Based on the answers, a score is calculated for both motivation tendencies. The difference between the sums of both tendencies is the performance motivation score. As established and tested by the authors [14] a score above 0 indicates higher motive to approach success (AS) while a score below 0 indicates a higher motive to avoid failure (AF). The MMG is an instrument with which a motive is judged as a stable variable. As other trait variables, such as personality traits, it can be assumed that motive manifestation is permanent.

To manipulate participants' action-outcome expectancy, we developed a cover story. Participants were told that an effect of matrix color on BCI performance was found when using the P300 speller. The goal of the study would be to further investigate this finding. Therefore, the participants should spell the same words using three different matrix colors (red, green, blue). Participants were randomly assigned to one of six groups. In each group, the difficulties assigned to a color changed such that each color (red, green, blue) was assigned to each difficulty (easy, moderately difficult, and difficult). Physically, all matrices were of the same luminance to avoid real color effects on BCI performance. Only the cover story suggested three different difficulties where spelling with the matrices was of equal difficulty in all conditions. For calibration, participants spelled two words (BRAIN and POWER). For the copy-spelling runs, participants spelled six five-letter words in each spelling difficulty condition without receiving feedback. Data of all difficulty conditions were aggregated based on the respective task difficulty irrespective of the colors that were assigned to the difficulties.

P300 speller and stimuli. A 6x6 P300 speller matrix was used which included the letters of the alphabet, the numerals 1 to 9 and an underscore. For calibration, we used ten flash sequences. During copy-spelling, we used two sequences to avoid ceiling effects found in an earlier BCI study [15]. Flash duration was 62.5 ms and the inter-stimulus-interval was 250ms. The inter-trial-interval was 2500ms. Flash color was white as a positive effect of a colored matrix together with colored flashes on performance was suggested [16] and we did not intend to really manipulate task difficulty. The word to spell appeared in a line above the matrix and the letter to spell was displayed in parentheses next to the word to spell. For data acquisition and experimental control, we used the BCI2000 Software [17].

EEG data acquisition. For EEG measurement we used a g.USB amplifier (Guger technologies, Austria) with a low pass filter of 60Hz, a highpass filter of 0.1 Hz and a notch filter of 50Hz. We placed 12 Ag/AgCl ring electrodes on the positions Fz, FCz, C3, Cz, C4, CPz, P3, Pz, P4, PO7, PO8 and Oz. The right mastoid was used as reference, the left mastoid as ground. Impedances were kept below 5kΩ. To control for eye movement artefacts, four EOG electrodes were added.

Data analysis. EEG data were analyzed using BrainVision Analyzer Software. Data were artifact corrected (above 50 µV amplitudes), and baseline corrected (-100 ms). The P300 detection was performed semi-automatically with peak detection in a time window of between 250 and 600 ms after stimulus onset. For the research question addressed here, we used electrode position Pz. Statistical analysis was conducted with IBM SPSS © version 24. Concerning our statistical analysis we would have needed 60 participants when assuming a medium effect with a power of .8 and a significance level of α=.05. Our data met the criteria for parametric testing, however, the required sample size was not fulfilled.

RESULTS

To investigate our hypotheses we applied a mixed model with achievement motive as between subjects' factor and perceived difficulty as within subjects' factor. The dependent variables were the P300 amplitude and the performance in percent correct responses.

Mean performance ranged between 57% and 64% correct selections. Performance was not affected by the suggested difficulties ($F(2)=.06$, $p=.93$), and not by the achievement motive ($F(2)=1.72$, $p=.19$); the interaction was also not significant ($F(4)=1.84$, $p=.14$). For the P300 amplitude, we found a main effect of perceived difficulty ($F(2)=7.77$, $p<.01$) but no main effect of achievement motive ($F(2)=1.76$, $p=.19$).

The P300 amplitude found in the moderately difficult condition was lowest (M_{AS} = 6.10 µV, SD=3.13, M_{AF}=6.43 µV, SD=1.87, see fig. 2 and 3). It was found to be significantly lower as compared to the condition perceived easiest ($F(2)=13.01$, $p<.01$) in which highest P300 amplitudes were shown in both groups (M_{AS} = 6.85 µV, SD=2.81, M_{AF}=7.75 µV, SD=1.58, see fig. 2 and 3). In the difficult condition, P300 amplitudes were moderately high (M_{AS} = 6.54 µV, SD=2.39, M_{AF}=7.40 µV, SD=2.02, see fig. 2 and 3).

Irrespective of suggested difficulty, on average, the AS tendency group had P300 amplitudes of M=6.50 µV (SD=2.63) and the AF group showed P300 amplitudes of M=7.19 µV (SD=1.60).

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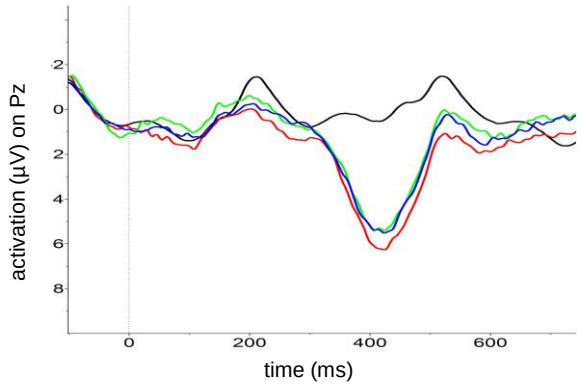

Figure 2: P300 amplitude for the approach success (AS) group. Black=non-targets averaged, red=condition perceived easy, green=condition perceived moderately difficult, blue=condition perceived difficult.

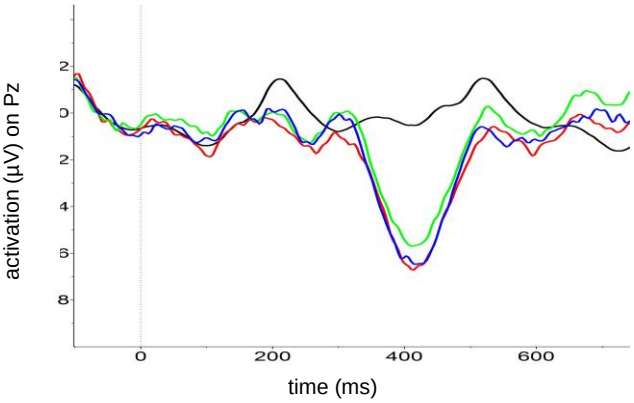

Figure 3: P300 amplitude for the avoid failure (AF) group. Black=non-targets averaged, red=condition perceived easy, green=condition perceived moderately difficult, blue=condition perceived difficult.

DISCUSSION

In this study, our goal was to investigate the effect of action-outcome expectancy and achievement motive in a BCI setting. We hypothesized action-outcome expectancy to affect P300 spelling performance and P300 amplitude and that there would be an interaction of this effect with achievement motive. While people who avoid failure should perform worst and show lowest P300 amplitudes in the condition suggested to be moderately difficult, we hypothesized that people who approach success to perform best and to show highest P300 amplitudes in this same condition.

We found no interaction of achievement motive with perceived difficulty. However, participants with the motive to avoid failure showed on average higher P300 amplitudes as compared to participants with the motive to approach success. We reject our hypothesis that participants who approach success to perform best in the condition perceived as moderately difficult and to show highest P300 amplitudes in this condition. Both groups showed highest P300 amplitudes in the condition perceived as easy. Irrespective of achievement motive, we see an effect of suggested difficulty on P300 amplitude even though this effect is not strong enough to affect performance on the behavioral level. It might be that our sample size was too small and potentially existing effects were not revealed in this data set.

Both groups of participants showed highest P300 amplitudes in the condition perceived as easy. Concerning performance, participants with a high motive to avoid failure performed best in the condition perceived as moderately difficult, while participants with the motive to approach success performed best in the condition perceived to be easy. These results are not in line with Atkinson's assumptions postulated in his theory of achievement motivation [4]. However, performance in this study was rather low and ranged between 57% and 64% correct. The number of event-related potentials to average might have been too small overall and therefore we possibly could not detect potential effects on performance.

It must be mentioned that Atkinson's theory was already challenged in the past. To name just two examples, self-efficacy beliefs [18], and interest [19] were found to influence performance motivation and therefore, to play a role in performance situations. In this study, we did not investigate other psychological variables that might affect achievement motivation. Especially, the role of incentives should be elucidated further as in a BCI spelling situation the incentive of a task might change according to personal performance expectancy [2]. Additionally, in a BCI situation not only performance motivation might be activated but also motivation components such as the need for affiliation [20]. Most participants ask about the goal of BCI research and the clinical applications and might experience compassion for the patients who are BCI end-users. Such influencing variables should be considered in future work.

Overall, there seems to be an effect of action-outcome expectancy on the P300 amplitude and expectancy value theories of motivation seem to be applicable in a BCI context [21]. Future research not only should address individual motives possibly influencing the perception of BCI situations, but also address explicit as implicit components of achievement motivation in a BCI situation. Only by identifying and investigating factors influencing BCI performance [22, 23], variance in BCI performance that can be explained by psychological factors, can be integrated into a theoretical framework [24] on the effect of motivation in BCI performance [21].

CONCLUSION

Performance expectation does influence BCI performance on a psychological level. More studies with higher numbers of participants are required to finally judge the influence of motivation on BCI performance. Creation of a theoretical framework on the

effect of motivation in BCI performance seems useful and indicated.

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