International Journal of Medical, Medicine and Health Sciences
ISSN: 2517-9969
Vol:9, No:7, 2015

EEG Correlates of Trait and Mathematical Anxiety during Lexical and Numerical Error-Recognition Tasks

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Abstract**—**EEG correlates of mathematical and trait anxiety level were studied in 52 healthy Russian-speakers during execution of error-recognition tasks with lexical, arithmetic and algebraic conditions. Event-related spectral perturbations were used as a measure of brain activity. The ERSP plots revealed alpha/beta desynchronizations within a 500-3000 ms interval after task onset and slow-wave synchronization within an interval of 150-350 ms. Amplitudes of these intervals reflected the accuracy of error recognition, and were differently associated with the three conditions. The correlates of anxiety were found in theta (4-8 Hz) and beta2 (16-20 Hz) frequency bands. In theta band the effects of mathematical anxiety were stronger expressed in lexical, than in arithmetic and algebraic condition. The mathematical anxiety effects in theta band were associated with differences between anterior and posterior cortical areas, whereas the effects of trait anxiety were associated with inter-hemispherical differences. In beta1 and beta2 bands effects of trait and mathematical anxiety were directed oppositely. The trait anxiety was associated with increase of amplitude of desynchronization, whereas the mathematical anxiety was associated with decrease of this amplitude. The effect of mathematical anxiety in beta2 band was insignificant for lexical condition but was the strongest in algebraic condition. EEG correlates of anxiety in theta band could be interpreted as indexes of task emotionality, whereas the reaction in beta2 band is related to tension of intellectual resources.

Keywords**—**EEG, brain activity, lexical and numerical error-recognition tasks, mathematical and trait anxiety.

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I. Introduction

MATHEMATICAL ANXIETY (MA) is defined as a feeling of tension, apprehension, or fear that interferes with math performance [1]. People with high MA level feel a fear during learning or examinations, whereas the people with low MA don't worry in such situations. Trait anxiety (TA) reflects the personal inclination to estimate an environment as potentially dangerous [2]. According to the Gray & McNaughton conception [3], TA is not directly related with fear. Fear is an aspiration to avoid some traumatic situations, whereas trait anxiety reflects personal estimation of the risk degree without relation to avoiding. Oppositely, the MA is directly related with fear and intention to avoid unpleasant situations during mathematical learning [1]. It is known, that the high TA level can be associated with activation of voluntary attention while deciding cognitive tasks [4], whereas MA has negative association with cognitive abilities [5]. However, the question about interaction between these personality traits is still under debates. The other undecided question is whether MA has specific association only with mathematical tasks or it is related to all kinds of testing during educational process?

Our study is aimed at comparing the EEG correlates of MA and TA in healthy students. Earlier it was revealed [6], that in many experimental tasks the TA level is reflected in EEG reactions in the theta (4-8 Hz), alpha (8-12 Hz) and beta (12-30) frequency ranges. The theta synchronization usually reflects the activity of working memory system and emotional appraisal of stimuli, the alpha desynchronization is associated with the general level of attention, whereas the beta desynchronization correlates with degree of intellectual tension during task execution. In this study, we compared EEG correlates of two kinds of anxiety during accomplishing error recognition tasks in three experimental conditions – performing lexical tasks in native language (lexical condition), performing arithmetic tasks (easy numerical condition), performing algebraic tasks (difficult numerical condition). We assumed that the interrelations between different kinds of anxiety and brain activity indexes of these processes will differ from each other that will allow make the conclusion concerning the differences of neuronal mechanisms of these psychological properties. Also we assumed that EEG correlates of MA will depend on kind of experimental condition that will reveal the specificity of MA to mathematics.

II. Participants and Procedure

A. Participants

Fifty-two neurologically normal adults (age 24.6 ± 2.91; 28 males; 1 left-handed) participated in this study. All participants are Russian native speakers; they were recruited at the Tomsk State University, and gave informed written consent prior to the experiment. The study was approved by the Psychology Research Ethics Committee at Tomsk University. Russian version of C.D. Spielberger State-Trait Anxiety Inventory was used for TA measure [7]. The Revised Math Anxiety Rating Scale was applied for MA measure [8]. By using of medial split of questionnaire's results, the participants were divided in two groups: 1) with low trait anxiety level (low TAL); 2) with high trait anxiety level (high TAL). By the same way, the participants were also divided in groups with low and high MA level (low MAL and high MAL).

B. Experimental Procedure

90 tasks were selected for the experiment. 30 trials contained the lexical tasks (a search of syntactical error in Russian sentence), 30 trials contained arithmetical tasks, and 30 trials contained algebraic example. Half of the tasks contained an error. Each stimulus was presented during 4 s. Correct and incorrect samples were presented randomly with inter-trial interval varying between 4 and 7 s. Also, the order of tasks from different conditions was randomized. During the EEG experiment, each participant sat comfortably in a chair with opened eyes in a dimly lighted soundproof room. The tasks were presented in white and black (Arial, 36pt) via a 24.4 cm x 18.3 cm monitor located 60 cm away in front of a participant. Participants were instructed to judge whether the presented sample contains an error. Participant indicated his/her decision concerning the sample by pressing one of two buttons (right hand if the sample was correct or left hand if the sample contained an error). Participants had three practice trials before task execution. Participants were instructed to make a response as quickly as possible. EEG was recorded continuously.

III. EEG Recording and Processing

A. EEG Recording

The signals were amplified using Brain Products GmbH (Germany) amplifiers (www.brainproducts.com). EEGs were recorded using 128 channels (127 EEG + VEOG) via Ag/AgCl electrodes, with 0.1–100 Hz analog bandpass filtering and digitized at 1000 Hz. The EEG electrodes were placed according to the extended International 10–10 system using Quik-Cap128 NSL and referred to Cz with ground at FzA. Electrodes impedance was maintained below 20 kΩ.

To assess changes in brain activity associated with error recognition in different conditions, event-related spectral perturbations (ERSPs) were computed using the EEGLAB toolbox [9]. EEGs were re-referenced to the average reference and epoched using intervals from 1.0 s before to 3.0 s after the task onset. The Morlet wavelet transformation was applied to segmented EEG to obtain time-frequency representation of EEG time series. Intervals from -1.0 to -0.25 s relative to the task onset were used for ERSP baseline correction. Artifacts resulted from eye movements; blinks, muscle electrical activity, and line noise were cleaned by independent component analysis (ICA) [10]. A separation of brain activity from artifacts was performed by an automatic approach based on the reference signals in the VEOG, Fp1 and Fp2 channels. After the ICA preprocessing, ERSP indexes were computed for each participant, separately for each experimental condition at each channel. In all, 189 frequencies were computed from 1.0 Hz to 44.9 Hz.

Individually computed ERSPs were averaged across all participants, channels separately for each experimental condition to obtain the general pattern of brain activity (Fig. 1). The random permutation method with $p<0.05$ significance level was applied in the statistical analysis of ERSPs for all conditions. The time-frequency intervals of interest for further analysis were selected by visual inspection of the averaged ERSP plot.

Statistical data processing: EEG channels were grouped into nine regions: left (10 channels), midline (11), and right frontal (10); left (17) and right temporal (17); all central (27); left (11), midline (12) and right occipital-parietal (11). ERSPs were averaged across channels within each region for each individual participant. For each time-frequency interval, repeated measures ANOVA with the Greenhouse-Geisser correction was applied to test the main effects of such factors as “correctness” (task with error vs task without error), condition (lexical vs arithmetic vs algebraic tasks), sagittality (anterior vs central vs posterior cortical regions), laterality (left vs medial vs right cortical regions), mathematical anxiety level (MAL, lower than median split vs higher than median split), trait anxiety level (TAL, lower than medial split vs higher than median split) and interactions between these factors.

IV. Results

ERSP pattern for error recognition task was firstly investigated without reference to the experimental conditions. An increase of EEG spectral power related to baseline (synchronization) in the frequency range 1-8 Hz was found at approximately 150-300 ms after task onset (See Fig. 1). In addition, spectral power decreased (desynchronization) within 8-20 Hz band during 300-3000 ms after task onset.

Based on visual inspection of average and individual ERSP patterns, the time-frequency intervals of interest were selected for the comparison of reactions of people with different MA and TA level. Two periods (150-300 and 500-2700 ms after task onset) were further analyzed using ANOVA. For the 150-300 ms period, the frequency bands 1-4 (delta), 4-8 (theta) and 1-8 Hz were chosen; for the 500-2700 ms period, the frequency bands 8-12 (broad alpha), 8-10 (lower alpha), 10-12 (upper alpha), 12-16 (beta1), 16-20 (beta2) and 20-25 (beta3)

Hz were chosen. ERSP values within each interval were averaged across trials, time-frequency points and electrodes within respective region separately for each participant and were used in repeated measures ANOVA. However, significant EEG correlates of MA and TA were revealed only in theta (4-8 Hz), beta1 and beta2 frequency ranges.

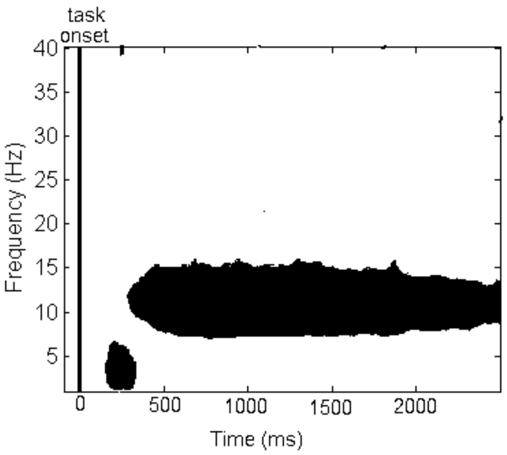

Fig. 1 General ERSP pattern for all experimental conditions

In theta frequency band (4-8 Hz) and 150-300 ms time interval the main effects of such factors as correctness, mathematical and trait anxiety were insignificant. The main effect of condition was marginal, F(2, 98) = 2.39; p = 0.097. The interaction between factors of correctness and MAL was marginal, F(1, 49) = 2.99; p = 0.090.

The main effects of sagittality, F(2, 98) = 14.56; p < 0.0001, and laterality, F(2 98) = 24.27; p < 0.0001, were highly significant. Theta synchronizations had the highest amplitude in posterior cortical regions (1,21±0.16) in comparison with anterior (0.93±0.13) and central (0.90±0.11) regions. Also, the amplitude of this reaction was lower in left hemisphere (0.84±0.13) in comparison with medial (1.18±0.14) and right (1.03±0.13) cortical regions.

The interaction between such factors as condition and MAL was significant, F(2, 98) = 4.34; p = 0.017. The people with lower and higher MA differed in that synchronization in lexical condition (low MAL 0.92±0.21; high MAL 1.36±0.20, p < 0.05), but didn't differ in arithmetic (low MAL 0.96±0.20, high MAL 0.94±0.19) and algebraic (low MAL 1.01±0.20, high MAL 0.90±0.19) conditions. Also, the interaction between trait anxiety level and laterality was significant, F(2, 98) = 3.79; p = 0.026. The people with lower and higher anxiety level didn't differ in theta amplitude in left hemisphere (low TAL 0.87±0.17, high TAL 0.89±0.19), but differ in right hemisphere (low TAL 0.92±0.18, high TAL 1.13±0.19), where the people with higher TAL had higher theta synchronization amplitude than that the people with lower TAL.

The repeated measure ANOVA with such factors as condition, sagittality, laterality, MAL and TAL was applied separately for processing EEG reactions after tasks with error and tasks without error. For both kinds of tasks, the main effects of sagittality and laterality were highly significant (p< 0.001). Cortical topography of theta band synchronization was the same with previous analysis. The main effect of condition was significant for tasks without errors, F(2, 98) = 3.93; p = 0.024, and insignificant for tasks with errors (p = 0.69). For correct tasks, the amplitude of theta synchronization was higher in lexical condition (1.23±0.15) in comparison with arithmetic (0.88±0.17) and algebraic (0.98±0.16) conditions.

The interactions between factors of condition on sagittality, F(4, 198) = 4.57; p = 0.002, and MAL on sagittality, F(2, 98) = 3.42; p = 0.045, were significant for correct tasks. Inter-conditional differences in theta synchronization were significantly detected (p < 0.05) in anterior cortical areas and were not found in central and posterior cortex. The effect of MAL was significant in anterior (low MAL 0.80±0.21, high MAL 1.11±0.20, p < 0.05) and posterior cortical areas (low MAL 1.07±0.25, high MAL 1.41±0.23, p < 0.05), but insignificant in central cortex (low MAL 0.91±0.18, high MAL 0.91±0.17, p = 0.69). The amplitude of theta synchronization for correct tasks was higher in people with higher MAL.

The interactions between such effects as condition on MAL, F(2, 98) = 3.28; p = 0.044, laterality on TAL, F(2, 98) = 3.70; p = 0.029, and condition on TAL on MAL, F(2, 98) = 3.07; p = 0.053, were significant for tasks with error. For incorrect lexical tasks, theta synchronization was significantly (p< 0.05) higher in people with high MAL (1.24±0.22) in comparison with lower mathematical anxious people (0.86±0.23). In opposite of incorrect algebraic tasks of theta amplitude was significantly (p < 0.05) higher for people with low MAL (1.05±0.21) in comparison with high MAL (0.82±0.20) people. For such kind of arithmetic tasks, differences between low and high MAL were same as for algebraic task (low MAL 1.11±0.20, high MAL 0.91±0.19, p < 0.05) (see Fig. 2).

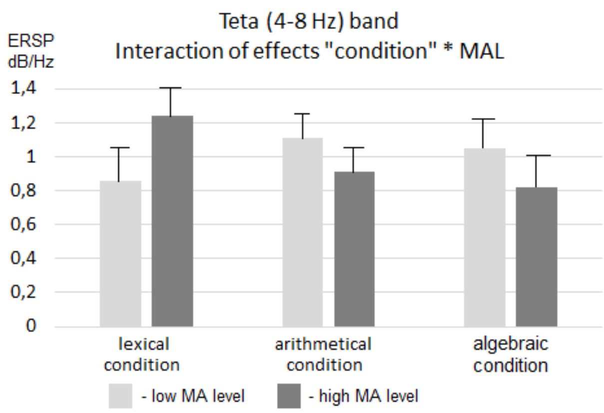

Fig. 2 The differences between people with low and high MAL in three experimental conditions in theta synchronization

Significant differences between people with low and high TAL were found in right hemisphere (low TAL: 0.86±0.17, high TAL: 1.20±0.19) and in medial cortex (low TAL: 1.07±0.19, high TAL 1.24±0.20), but were not found in left hemisphere (low TAL: 0.77±0.17, high TAL: 0.83±0.18).

International Journal of Medical, Medicine and Health Sciences
ISSN: 2517-9969
Vol:9, No:7, 2015

Theta amplitude was higher in people with high TAL in comparison with lower TAL people.

Three factors of interaction showed that in tasks with error under low MAL the amplitude of theta synchronization was significantly ($p < 0.05$) higher for people with high TAL in algebraic (low TAL: 0.61±0.28, high TAL: 1.48±0.31) and arithmetic (low TAL: 0.78±0.27, high TAL: 1.44±0.30), but not in lexical tasks (low TAL: 0.87±0.31, high TAL: 0.84±0.35). Under high MAL the interaction between factors condition and TAL was insignificant ($p = 0.568$).

In beta1 (12-16 Hz) band and 500-2700 ms time interval, the interactions between effects of MAL and TAL were significant for tasks without errors, $F(1, 49) = 4.09$; $p = 0.049$, and marginal for tasks with errors, $F(1, 49) = 3.03$; $p = 0.088$. For correct tasks, in people with high MA the stronger amplitude of beta1 desynchronization was associated with lower TAL (low TAL: -2.72±0.37, high TAL: -1.58±0.47), whereas in people with low MA the stronger amplitude was associated with higher TAL (low TAL: -1.67±0.37, high TAL: -2.06±0.37). Same differences were found in beta2 (16-20 Hz) band and 500-2700 time interval. In this band, the interaction between MAL and TAL was also significant for task without errors, $F(1, 49) = 5.020$; $p = 0.030$, and insignificant for tasks with errors ($p = 0.162$). Thus, the effects of MAL and TAL on beta1 and beta2 desynchronization were the opposite between each other, but it was significant only for correct tasks.

In addition, in beta2 band the main effect of correctness was insignificant, effects of condition, $F(2, 98) = 32.60$; $p < 0.0001$, sagittality, $F(2, 98) = 68.34$; $p < 0.0001$ and laterality, $F(2, 98) = 19.78$; $p < 0.0001$, were highly significant for all kinds of tasks (correct, incorrect and both). Beta2 desynchronization had the strongest amplitude in algebraic condition (-1.30±0.10) in comparison with lexical (-0.82±0.08) and arithmetic (-0.99±0.09) conditions. The beta2 amplitude was strongest in posterior cortical regions (-1.43±0.12) in comparison with anterior (-0.77±0.08) and central (-0.90±0.07) conditions. Also, this reaction was stronger in midline cortex (-1.20±0.10) than that in left (-0.93±0.08) and right (-0.97±0.08) hemispheres. The interaction of correctness on condition was marginal, $F(2, 98) = 4.88$; $p = 0.063$. Beta2 desynchronization was different between correct and incorrect arithmetic tasks (for correct: -1.02±0.11, for incorrect: -0.95±0.09), but didn't differ for correct and incorrect tasks in lexical and algebraic conditions.

Interactions between effects of condition on MAL, $F(2, 98) = 3.75$; $p = 0.028$, was significant for tasks with errors, but not for correct tasks. In lexical condition there are no differences between people with low and high MAL (low MAL: -0.80±0.14, high MAL: -0.79±0.13). In arithmetic condition the amplitude of beta2 desynchronization was higher for people with higher MAL (low MAL: -0.85±0.14, high MAL: -1.05±0.13), whereas such amplitude was higher for people with lower MAL in algebraic condition (low MAL: -1.52±0.16, high MAL: -1.26±0.15) (See Fig. 3).

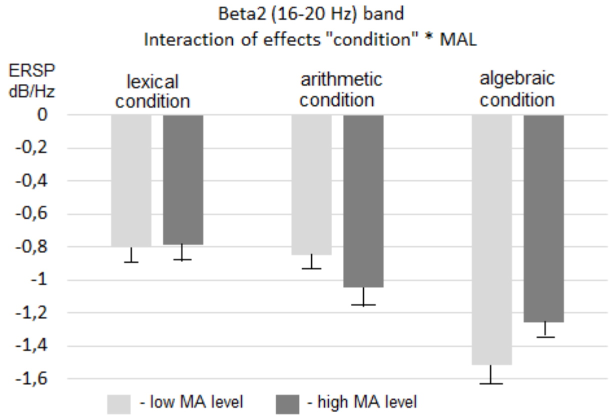

Fig. 3 The differences between people with low and high MAL in three experimental conditions in beta2 desynchronization

V. Discussion

Short-term synchronization in theta band under stimuli recognition could be interpreted either as an indexes of working memory activation [11] or as a reaction related to emotion appraisal [12]. Amplitude of theta-synchronization is higher for recognition of emotional-related stimuli in comparison with non-emotional stimuli. In our case, the amplitude of theta synchronization for all conditions was the strongest in posterior region of right hemisphere that corresponds to cortical topography of limbic system projections [13]. The effect of MA was most strongly expressed in the anterior and posterior, but not central cortical regions that also correspond to data about cortical topography of the emotional-related reactions. For lexical tasks a theta amplitude was stronger than that for the numerical tasks. This effect was more significant for tasks without errors, than for tasks with errors. Such inter-conditional differences could be interpreted as an index of higher emotionality of language tasks in comparison with numerical ones for most of participants. In tasks with errors significant differences of MA level were revealed for different experimental conditions. In lexical conditions higher MA was associated with higher amplitude of theta synchronization, whereas for arithmetic and algebraic conditions, on the contrary, higher amplitude was revealed in the people with lower MA level. It is possible to assume that the high MA level is associated with increase of emotionality while recognize errors in lexical tasks, with reduction of emotionality during recognition errors in numerical tasks. The effects of the TA level were revealed in all experimental conditions in the right hemisphere which is more related with emotions, than the left hemisphere [14]. In the people with higher TA level the right-hemispherical amplitude of theta synchronization was higher, than in people with lower TA level. In the opposite of MA, the general effect of TA was more strongly expressed in recognition of incorrect arithmetic and algebraic tasks, but not lexical tasks. The MA level modulated the effect of TA in recognition of tasks with errors. In the people with low MA level the effect of TA was revealed, but such TA effect was not found in the people with high MA level.

In general, the result in the theta range could be interpreted as an index of relationship of MA with appraisal of emotionality of stimuli during the testing of participant. MA is related to increase of emotions while performing lexical tasks and with weakening of emotions in solving difficult mathematical tasks, but it almost not related to emotions during the execution of simple arithmetic tasks. The TA level influences on the relations between left and right hemispheres. It is possible to assume that the high MA level is related to fear of mathematical testing that suppresses emotionality in the people with high TA level, but doesn't influence on the people with low TA level.

Indexes of beta1 and beta2 desynchronization are interpreted as correlates of tension of intellectual resources under execution of cognitive tasks [15]. In our case, the higher beta2 amplitude always corresponded to difficult numerical tasks in comparison with easy numerical and lexical conditions. In contrast to a theta synchronization, the effect of MA on beta2 desynchronization was found for numerical, but not for lexical tasks. For tasks with errors, higher amplitude of beta2 desynchronizations was observed in the people with high MA level under arithmetic tasks decision, but, on the contrary, in the people with low MA level under execution of algebraic condition. The effects of MA and TA in beta1 and beta2 desynchronization were directed oppositely. It is possible to assume that high TA level strengthened the cognitive control over the tasks execution, and high MA level, on the contrary, decreased such control. Interpreting MA as a fear of testing, it is possible to conclude that such fear doesn't influence intellectual tension during the lexical testing (though strengthens an emotional tension), increases cognitive activity during performance of simple arithmetic tasks and weakens intellectual tension (also as well as an emotional tension) under the execution of difficult algebraic tasks.

VI. Conclusion

The EEG correlates of mathematical and trait anxiety level was revealed both in theta-band synchronization and beta1/beta2 band desynchronization. Theta synchronization could be interpreted as an index of emotional appraisal of task, whereas the beta-desynchronization reflects the cognitive processing of task. Mathematical anxiety could be interpreted as an index of fear, which has negative effects on processing of difficult numerical tasks, whereas higher trait anxiety has positive influence on such processing.

Acknowledgment

Authors are gratefully acknowledging the support from the №11.G34.31.0043 grant from the Government of the Russian Federation. Additionally, A.N. Savostyanov and A.E. Saprygin gratefully acknowledge the support from the №14-15-00202 grant from the Russian Science Foundation.

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