ELSEVIER Biological Psychology 40 (1995) 313–320

BIOLOGICAL PSYCHOLOGY

Frontal midline theta related to learning in a simulated driving task

Seppo J. Laukka*[a], Timo Järvilehto[a], Yuri I. Alexandrov[b], Juhani Lindqvist[a]

[a]*Department of Behavioral Sciences, University of Oulu, P.O. Box 222, FIN-90571 Oulu, Finland*
[b]*Institute of Psychology, Russian Academy of Sciences, Moscow, Russia*

Received 2 December 1993; revision received 11 March 1994; accepted 11 May 1994

Abstract

The occurrence of frontal midline theta activity (4–7 Hz) was studied in a simulated driving task during consecutive phases of goal-directed behaviour. Electrical activity of the forebrain (Fz) was analysed in a simulated traffic situation in which the subject had to find the correct way to drive a car through a set of roads in a computer game. The occurrence of theta activity was analysed during seven consecutive sections of the game. The results showed that the occurrence of theta activity increased during learning — successful behaviour produced more theta than unsuccessful behaviour. In some sections of the game the percentage of theta was larger than in others. It is suggested that the theta activity reflects relaxed concentration after mastering the game.

Keywords: EEG; Human; Theta rhythm; Performance

1. Introduction

Since Arellano and Schwab (1950) reported that theta rhythm (4–7 Hz) appeared in the human EEG during problem solving, several studies have been done on the relationship between theta rhythm and behaviour. The occurrence of this rhythm, particularly at the frontal midline, has been observed during different kinds of cognitive tasks (Ishihara & Yoshii, 1972; Mizuki et al., 1982; Lang et al., 1987),

* Corresponding author, Tel.: +358 81 5533658; Fax: +358 81 5533600; E-mail slaukka@ktk.oulu.fi.

SSDI 0301-0511(95)05122-Q

transcendental meditation (Herbert and Lehman, 1977), and during REM sleep (Hayashi et al., 1987). Theta rhythm has also been reported to be related to personality traits (Mizuki et al., 1984).

Mizuki et al. (1982) reported that during a tracking task theta rhythm appeared most frequently in the more difficult parts of the game, or when a large number of errors occurred. The authors concluded that theta was related to the degree of task difficulty. The level of concentration appeared to determine the amount of theta activity. Lang et al. (1987) also showed that the mean power density of the theta activity was enhanced in periods of learning compared to resting in a spatial visuo-motor task. Theta activity was also related to the level of performance — good learners had a larger increase of theta than poor learners. These results suggest a relationship between the appearance of theta activity and the dynamics of performance.

These studies, however, do not provide the behavioural significance of theta rhythm, because their experimental set-up did not allow examination of the specific relationship between the appearance of theta activity and the quality of performance during different phases of behaviour.

In the present study the appearance of theta was studied in a situation in which the behavioural content of the different phases of the task could be determined. The relationship between the amount of theta activity and development of performance was investigated by using a task consisting of a sequence of interdependent behavioral phases, ending with immediate feedback on the quality of the subject's performance. This study is part of a more comprehensive investigation of the organisation of the brain and human behaviour under normal conditions and under the influence of alcohol.

2. Methods

2.1. Subjects

The subjects were six healthy men (age range 19–31 years). The experiments were carried out on 2 consecutive days during the first half of the day. One subject was excluded for the first day because of defective videorecording.

2.2. Experimental situation

Electrical activity of the brain was studied in a simulated traffic situation in which the subject had to find the correct way to drive a car through a set of roads in a computer game (see Fig. 1). Only one section of the road (38 × 84 cm) was visible. The car was fixed, and the scene was rolling. The subject could control only the lateral movement of the car with a joystick. The speed of the rolling scene was fixed (30.4 cm/s). At the first crossroads the subject had to follow a traffic sign (1st sign, duration of presentation 2.8 s) indicating one of three roads (A, B or C). At the second crossroads a choice had to be made between four roads (1,2,3 or 4) on the basis of the second traffic sign (2nd sign, duration of presentation 2.1 s). The second sign was an arrow pointing either to the right or to the left. The meaning of the sign was de-

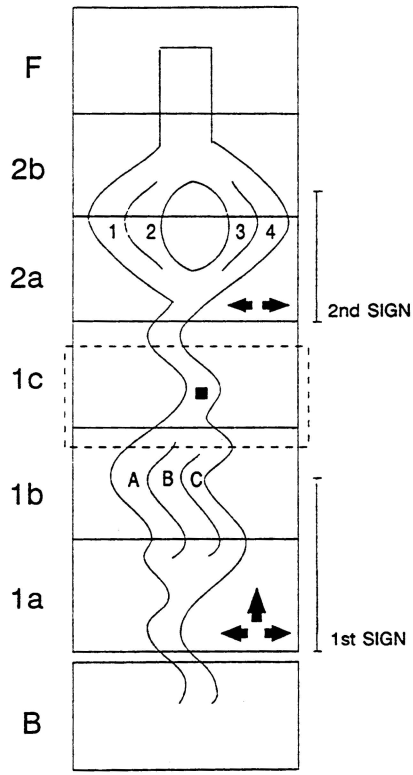

Fig. 1. Scheme of the consecutive road sections in the simulated driving task (B, 1a, b, c, 2a, b, F). B, beginning; 1, appearance of the 1st sign; 2, appearance of the 2nd sign; F, feedback. The dotted rectangle indicates the rolling scene (38 × 84 cm) and the black square, the car.

pendent on the road used at the first crossroads. Thus, for each road A, B and C, there was one correct pair of the second roads corresponding to the right-left traffic signs. The corresponding roads were: A, 2 and 3; B, 3 and 4; and C, 1 and 2. The different traffic signs were presented in random order. If the correct road was chosen and there were not too many driving mistakes (i.e., driving outside the road) then, at the end of the game a "garage door" opened indicating successful driving. After the appearance of the opened or closed garage door, feedback was given. At the right side of the screen one of the following letters were presented (abbreviations of Finnish words): O (correct), V (too many driving errors), T (incorrect road was chosen) or VT (too many driving errors and incorrect road). To obtain a comparable ratio between the number of positive and negative feedbacks for different subjects, the criteria for the number of mistakes was adapted depending on subject's performance. Each trial lasted about 10 s with a pause of 2 s between trials. The driving performance was analysed on the basis of correct/incorrect road selections and driving errors.

There were two sessions on 2 consecutive days. In the *learning session*, the subject had to learn the meaning of the different traffic signs by trial and error. The subject drove on road B until he had found the correct way (BL-condition). After this, the subject practised on road B (BP-condition, 60 trials). Thereafter, roads C and A were similarly learned and practised (CL, CP, AL and AP conditions). Finally, a block of 180 trials was presented (ABC-condition), in which the different types of traffic signs were randomly chosen for presentation. On the second day the *experimental session* was run in two blocks of 180 trials (E1 and E2) with a pause of 15 min between the blocks. Before and after each block of trials, a 2-min resting EEG was recorded with eyes open and closed.

2.3. Recording methods and sampling

During the experiment the subject's face was recorded on videotape with the rolling scene mixed in the same picture. The performance of the subject could be visually monitored from the videorecordings. The computer also classified occasional driving mistakes at the 2nd crossroads as a wrong selection of the road. The selection of the road was scored as "correct" even if the subject had driving mistakes when entering the correct road. The correct performance was determined visually from the videorecordings. Those trials which could not be unequivocally classified as correct or incorrect selections of the road were excluded from further analysis.

The EEG from Fz and eye movements were recorded with an electrode just above the right eye. The reference was a combined A1 and A2, and the subject was grounded at the left wrist. The time constants of the EEG and EOG recordings were 2 s and the upper frequency limit 30 Hz. The EEG and EOG were sampled on-line with a frequency of 137 Hz starting 1 s before and ending 1 s after the trial. The recording system was calibrated before and after each experiment with standard pulses of 100 μV amplitude. The computer monitored and stored moments when driving errors occurred as well as selection of correct/incorrect road after the 2nd sign, and stored the feedback from each trial (O, V, T or VT). Additionally, for each trial, the computer stored the instant (event marks) driving commenced (B), the appearance of the 1st sign, the appearance of the 2nd sign and the feedback (F).

2.4. Data analysis

A trial was divided into seven 1610 ms observation sections (see also Fig. 1): a section (B) from the beginning of the driving, three consecutive sections (1a, b and c) starting from the appearance of the first traffic sign, two consecutive sections (2a and b) from the appearance of the second traffic sign, and one section (F) at the end of the trial. Length of the whole analysis period was 11.3 s.

EEG recorded during the trial were smoothed, their oscillation peaks determined, and intervals between the peaks measured. The occurrence of theta was accepted if at least two consecutive intervals matched the range of theta frequency (4–7 Hz). The duration (minimum 280 ms) of theta in each observation section was determined for each trial.

For each block of trials and observation sections, the percentage of occurrence of theta was calculated. Analysis of variance (ANOVA) was carried out with the following factors: nine conditions (BL–E2), seven sections and correctness (correct/incorrect). Differences between the conditions in the percentage of incorrect selections of the road were tested by *t*-test. The number of driving errors was analysed with an ANOVA containing conditions (nine) and sections (six — the last section with no driving was omitted).

3. Results

3.1. Driving performance

In the analysis of driving performance, learning and practice conditions were excluded due to too few incorrect selections of the road. The percentage of trials with incorrect road selections in the ABC-condition was 17.4%, 13.6% in the E1-condition and 11.6% in the E2-condition. There were significantly more incorrect selections in the ABC-condition than in the E1-condition ($t = -2.19$, $p < 0.05$) or in E2-condition ($t = -3.41$, $p < 0.001$).

The mean number of driving errors between subjects in the ABC-condition ranged from 0.17–3.96, in the E1-condition from 0.15–3.11, and in the E2-condition from 0–4.36. There were no significant differences between conditions. However, there were significant differences between the observation sections ($F = 18.38$, $df = 5$, $p <$

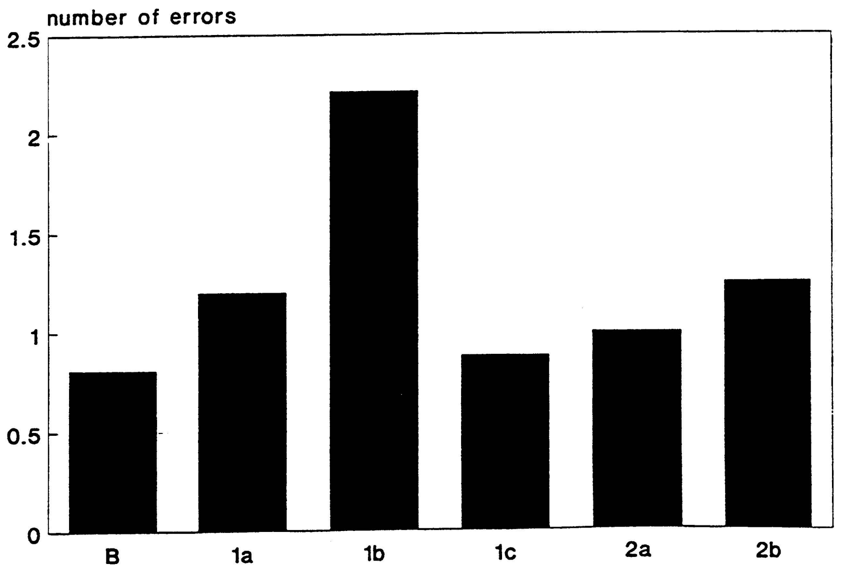

Fig. 2. Number of driving errors during sections of the task, averaged across ABC-, E1- and E2-conditions and subjects.

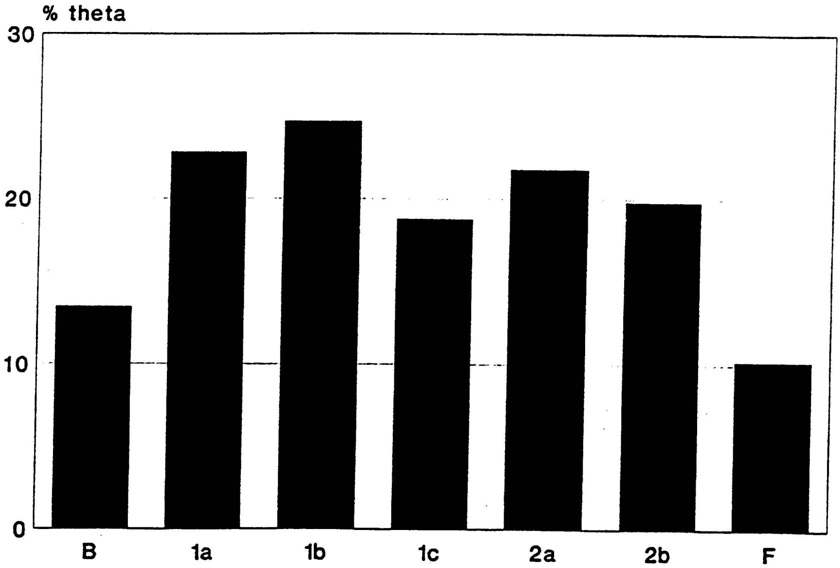

Fig. 3. Percentage of theta activity during sections of the task, averaged across ABC-, E1- and E2-conditions and subjects.

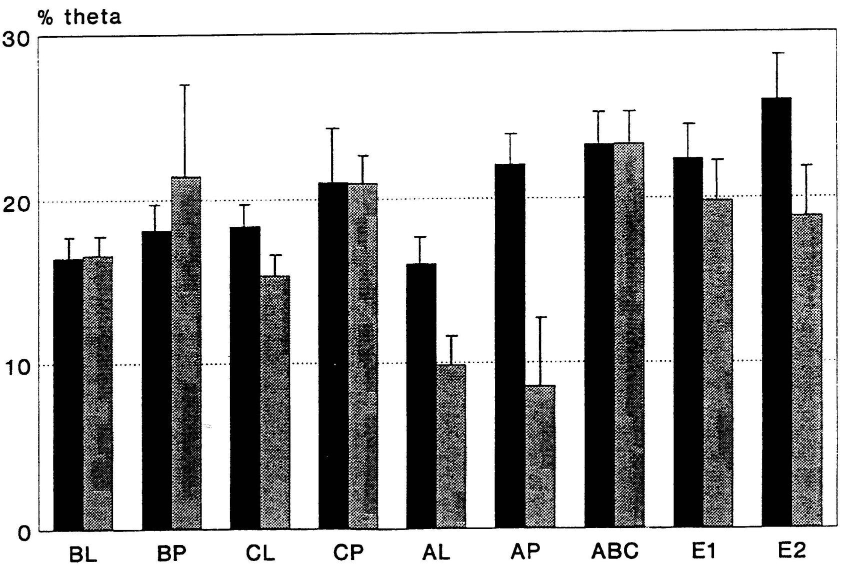

Fig. 4. Percentage of theta activity in different conditions (BL, BP, CL, CP, AL and AP are learning and practising roads B, C and A, respectively; ABC, practising all roads; E1 and E2, experimental sessions). The black column represents correct selection of the road and the hatched column, incorrect selection of the road. Standard error of the mean is also indicated.

0.001). The largest number of driving errors was found at section 1b (see Fig. 2). There was no significant section × condition interaction.

3.2. Theta activity during learning

Sections had a significant effect on theta activity ($F = 10.22$, $df = 6$, $p < 0.001$). Theta was most prominent during sections 1b and 2a (see Fig. 3). There was a significant increase in the percentage of theta activity from the first learning condition (BL) to the E2-condition ($F = 3.63$, $df = 8$, $p < 0.001$) (see Fig. 4)

More theta was found during correct than during incorrect road selections ($F = 6.80$, $df = 1$, $p < 0.01$). This difference was most prominent at the traffic signs as indicated by significant correctness × section interaction ($F = 2.55$, $df = 6$, $p < 0.05$). This difference became larger during learning as can be seen in Fig. 4. The difference (in percentage of theta) between correct and incorrect road selections increased in the practising condition (learning and practising), disappeared in the ABC-condition, and appeared again in the experimental sessions (conditions E1 and E2). However, the interaction between condition × correctness was not significant.

4. Discussion

In the present study a simulated driving task was used which consisted of a sequence of driving sections followed by immediate performance feedback. The results demonstrate that the occurrence of theta activity was most prominent in the sections immediately after the appearance of the first and the second traffic sign. More theta was observed during correct task performance. The percentage of theta increased during learning.

Why is the occurrence of theta activity related just to the observed phases of action? To answer this question we must first consider what kind of dynamic changes occur in the action of the subject during the learning of the task. Before the subject knows the alternative routes, his action consists of separate phases: driving to the first traffic sign, selecting the road accordingly, driving to the next sign, etc., and then finally using the feedback information to determine whether the selections were correct. In this phase of the learning process each action must be carried out separately, because the subject does not know yet which selection is correct.

The learning process leads to a change in the action structure of the subject. After learning, the subject already knows at the beginning of the trial what are the possible correct alternatives. Therefore, he already relates, at the beginning his entire activity, to the end of driving, and the traffic signs act only as symbols which eliminate unnecessary action possibilities. In this situation the increase of theta activity is most prominent in the sections after the traffic signs. Thus, when learning is completed, no decisions have to be made about the significance of the traffic signs — the traffic sign only indicates the action alternative to be realized. Thus, the period of the maximal occurrence of theta seems to be a period of relaxed concentration, i.e. the integration of action, after the appearance of the symbol, for taking the desired route. This interpretation is in accordance with earlier findings on the relationship of theta to transcedental meditation or concentration (see introduction). Thus, an increase of theta during learning reflects a gradual increase in mastery of the task, i.e. relaxation of the subject during performance.

If the increase of theta activity reflects development of a new organization of action during learning, it may explain why the difference in the amount of theta between the different phases of driving and the general increase of theta during the task develop from condition to condition (from BL to E2) (see Fig. 4). This is caused by the increase in the difference between the correct and incorrect behaviour at the beginning of driving. During repetition of the task the subject learns to retain all possible alternatives. If some of these are missing and the corresponding traffic sign appears, the result is a new organization after the traffic sign and the absence of relaxed concentration. Thus, with further practice, all driving alternatives can be held efficiently in memory, and the behavioural manifestation of this process is the improvement of performance from the ABC-condition to the E2-condition apparent from the decrease in the number of errors.

In conclusion, the relationship of theta activity to the behaviour of the subject and to the quality of his performance is due to (1) the formation of new organization of action, and (2) a gradual differentiation between correct and incorrect action related to the formation of driving alternatives at the beginning of the task. The appearance of theta activity appears to reflect the behavioral integration underlying the achievement of successful performance.

Acknowledgements

Supported by The Finnish Foundation for Alcohol Studies and by The Finnish Academy.

References

Arellano, A.P., & Schwab, R.S. (1950). Scalp and basal recording during mental activity. *International Congress of psychiatry*. Paris.

Herbert, R., & Lehmann, D. (1977). Theta bursts: an EEG pattern in normal subjects practising the transcendental meditation technique. *Electroencephalography and Clinical Neurophysiology*, 42, 397–405.

Hayashi, H., Iijima, S., Sugita, Y., Teshima, Y., Tashiro, T., Matsuo, R., Yasoshima, A., Hishikawa, Y., & Ishihara, T. (1987). Appearance of frontal mid-line theta rhythm during sleep and its relation to mental activity. *Electroencephalography and Clinical Neurophysiology*, 66, 66–70.

Ishihara, T., & Yoshii, N. (1972). Multivariate analytic study of EEG and mental activity in juveline delinquents. *Electroencephalography and Clinical Neurophysiology*, 33, 71–80.

Lang, M., Lang, W., Diekmann, V., & Kornhuber, H.H. (1987). The frontal theta rhythm indicating motor and cognitive learning. In R. Johnson, J.W. Rohrbaugh & R. Parasuraman (Eds.), *Current Trends in Event-Related Potential Research* (EEG Suppl. 40), (pp. 322–327). Amsterdam: Elsevier.

Mizuki, Y., Kajimura, N., Nishikori, S., Imaizumi, J., & Yamada, M. (1984). Appearance of frontal midline theta rhythm and personality traits. *Folia Psychiatrica et Neurologica Japonica*, 38, 451–458.

Mizuki, Y., Takii, O., Tanaka, T., Tanaka, M., & Inanaga, K. (1982). Periodic appearance of frontal midline theta activity during performance of a sensory-motor task. *Folia Psychiatrica et Neurologica Japonica*, 36, 375–381.