COMPLEXITY - DEPENDENT SYNCHRONIZATION OF BRAIN SUBSYSTEMS DURING MEMORIZATION

T. DÖRFLER*[1], A. SIMMEL[1], F.-M. SCHLEIF[1,2] & E. SOMMERFELD[1]

[1] Institute of General Psychology, University of Leipzig, Germany
[2] Institute of Computer Science, University of Leipzig, Germany
*corresponding author: psy96cdv@studserv.uni-leipzig.de

Abstract

In this article coherence analysis is used as an internal indicator of mental effort. Therefore, a working memory task was given as an external request. Test subjects had to memorize easy symbols. To obtain a complexity variation we only modified the number of symbols in three conditions (two, four and six symbols). Preliminary results show that coherence between functionally coupled brain subsystems reflect partial processes in course of complexity-dependent memorization of symbols. EEG analysis of coherence in frequency bands beta1 and theta shows different aspects of human information processes represented by different band characteristics.

Keywords: *working memory; EEG coherence analysis; beta1, theta frequency bands*

1 Introduction

Working memory is the ability to retain and associate information over brief time intervals (TESCHE et al., 2000). The cognitive processes underlying memory representation of magnitude and comparison of magnitude are fundamental, yet still purely understood also in psychophysics (ALGOM, 1998). In this paper, we examine the activity of the human brain during a short working memory task. Since both frontal and parietal brain subsystems are necessary for problem solving (SARNTHEIN et al., 1998), it seems helpful to regard functional coupling between frontal and parietal cortical areas. Therefore, we constructed a working memory task which can be varied from its complexity during the experiment. The more difficult (complex) this task will be the longer the mentioned functional coupling should be. Duration of this functional coupling is used to be an indicator for mental effort. EEG coherence was used to assess the synchronization of brain areas. We hypothesized that in dependence on increasing complexity of the working memory task the mental effort indicated by coherence duration between frontal and parietal areas is increasing too. Divers components of mental effort can be distinguished (SOMMERFELD, 1994). Short-term storage and online manipulation of information are involved in solving the given problem as shown below

(SOMMERFELD et al., 1999). In our study we investigated this coupling by using EEG coherence analysis based on the ARMA model (SCHACK et al., 1999). Thus, we should succeed in illustrating internal processes which are the equivalents for external indicators.

2 Method

Twelve healthy volunteers (aged between 19 and 30, 1 male, 11 females) with normal or corrected to normal vision participated in the experiment. During six sessions (one week intermission between two sessions) their EEG was recorded from 19 scalp electrodes using the international 10-20 system using *Neuroscan* at 200 Hz (see Figure 1).

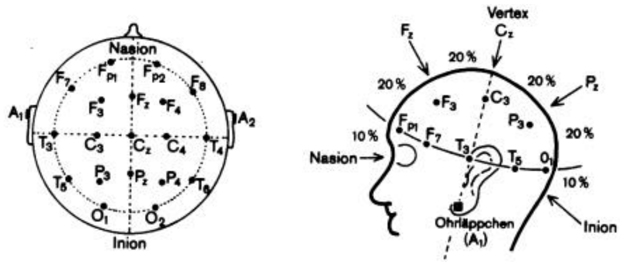

Figure 1: Scalp electrodes in international 10-20 system.

The experiment was conducted in three sections to investigate different components of human information processing:

I. "comparison process while memorization"
II. "memorization" (without comparison process)
III "comparison process" (without memorization).

A detailed description of the experiment "comparison process while memorization" is given in SIMMEL et al. (2001). Analysis of part III is still going on. In this paper, we only consider part II – *memorization*. In each session the students had to memorize symbol groups presented on a screen. These symbol groups can be classified into three categories by the number of symbols they consist of. Every category included 30 symbol groups. The symbols within one symbol group are generated randomly from a pool of eight different ones. Examples for every of this three categories are shown in Figure 2. For further explanations, we call them category 2 (two symbols in one symbol group), category 4 (four symbols in one symbol group) and category 6 (six symbols in one symbol group).

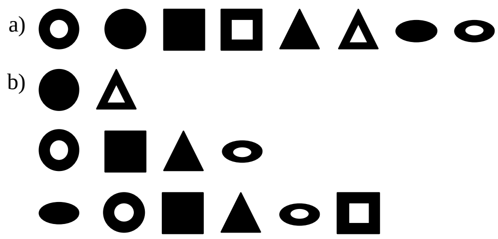

Figure 2: a) Item pool to generate pattern groups.
b) Examples for each category (two, four or six symbols) are shown.

The experiment was organised in the three blocks. First block consisted entirely of 30 category 2 symbol groups and were presented for 2000 ms on the screen. The second block consisted of 30 category 4 groups, presented for 3000 ms, and 30 category 6 groups for 4000 ms in the third block. Every symbol group presentation was followed by 2000 ms dark screen period while EEG of the test subjects was recorded. Fifteen times after the EEG recording, subjects were asked to draw the memorized symbol group. The drawing task was randomly distributed over the 90 cases.

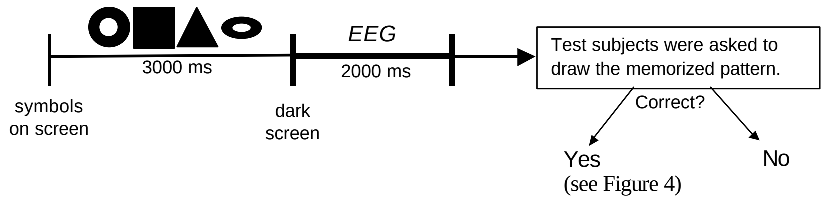

Figure 3: Experimental situation for category 4-condition: During 2000 ms EEG was recorded from 19 scalp electrodes.

For each subject the interregional coherence duration between certain frontal (*F3, Fz, F4*) and parietal (*P3, Pz, P4*) electrodes and error rate were analysed. Coherence duration is defined as the period of high coherence larger than a 0.65 threshold. This threshold resulted from an analysis of coherence histograms. The analyses were restricted to band coherence within the frequency bands *beta-1* (13-20 Hz) and *theta* (4-7.5 Hz), respectively. The *beta-1* frequency band is said to be sensitive determining mental effort due to a co-ordination processes while solving a problem (PETSCHE et al., 1998; SOMMERFELD et al., 1999). SARNTHEIN et al. (1998) and also JENSEN et al. (1998) postulate that the *theta* frequency band in human EEG reflects memory processes.

3 Results and Interpretation

3.1 Behavioural data

All test subjects were equally able to keep two symbols in mind for a duration of 2000 ms and to reproduce them almost error free at our request (see Figure 4).

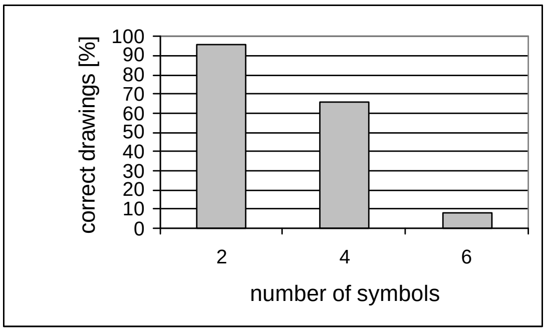

Figure 4: Percentage of correct recalled symbol groups for the different categories.

Each symbol can be classified regarding its shape (square, circle, ellipse, triangle) and its filling (filled, unfilled) and, additionally, its position in the symbols group. Hence, three dimensions have to be considered for each symbol obtaining error-free reproduction. At the latest, since MILLER (1956) we know that our short-term memory can keep a span of 7, plus or minus two units for a short time. If we assume that test subjects need for each symbol they memorize three memory units (shape, filling, position in order to the other symbols) for each symbol they memorize, then we come to the conclusion that error free reproduction of two symbols should be well possible. Facts concerning short-term memory capacity have to be borne in mind if one regards the number of correct solutions when memorizing four or six symbols. Remembering six symbols is the most difficult condition (compare Figure 4).

3.2 EEG data

For calculation of coherence duration, we considered only artefact-free trials. We used *SpecTrial/SpecPara,* computer tools developed by SCHACK et al. (1999) based upon the ARMA model (see also MÖLLER et al., 2001) which allow short space analysis in time. The analyses were restricted to band coherence within the frequency bands 13-20 Hz and 4-7.5 Hz, respectively. Nine frontal-parietal electrode combinations were evaluated. Except for electrode combination *F4P4* in the *beta-1* frequency band all curves show similar characteristics. Mean coherence duration under each condition represented by *FzP3* is shown in Figure 5. The following results were obtained by averaging over all subjects. The *H-test* (by KRUSKAL & WALLIS) was used for statistical calculations (significance level of 5 %).

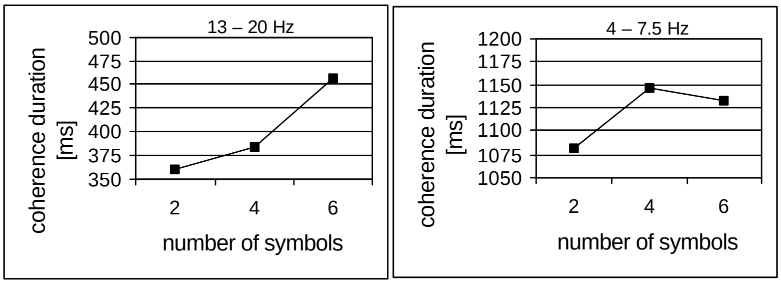

Figure 5: Coherence duration [ms] in two different frequency bands. Left the *beta-1* (13-20 Hz) frequency band and right the *theta* (4-7.5 Hz) frequency band.

a) *Beta-1* frequency band

Results for the b_1-band are presented in Figure 5 (left). Figure 5 shows coherence duration as a function of number of symbols to be memorized. While memorizing two symbols little mental effort is necessary to match this task. Mental effort during the category 4-condition seems to be on the same level as the category 2-condition (there is no significant difference). Coherence duration is significantly increasing when six symbols (category 6) are to remember. In the last condition, the brain areas represented by the scalp electrode *Fz* and by *P3* form a functional entity. Coordinated strong co-operation (over a threshold) of these cell assemblies takes up almost a quarter of time recorded. The more complex the task was, the more mistakes were made. In spite of that mental effort the subject's error rate is still increasing.

b) *Theta* frequency band

Figure 5 (right) shows coherence duration as a function of number of symbols to be memorized. Coherence duration is longer in the q-band than in b_1. There are significant differences between category 2 and category 4-condition. Results show a large difference between the *beta-1* and *theta* band switching from category 2-condition to category 4-condition. Coherence duration during category 2 and category 4 are in the *beta-1* band on the same level, while coherence duration in the *theta* band show a strong increase between those two categories. In our experiment, this was the most evident result that discriminated the reaction of these two frequency bands.

Memorizing of more than four symbols doesn't lead to an increase in coherence duration. The process is said to be capacity limited.

4 Discussion

Functional coupling between specific frontal (*Fz*) and parietal (*P3*) electrodes increases in dependence on complexity (difficulty) of a working memory task. Short-term storage and online manipulation of information are two components which are involved in task solving. Therefore, we can conclude that different processes are represented by the two frequency bands *beta-1* and *theta*. *Beta-1* seems to react on so-called control processes necessary in matching the task, in accordance with BADDELEY's Central Executive (BADDELEY, 1990). Memory functions seem to be reflected better by *theta* frequency band (JENSEN et al., 1998; SARNTHEIN et al., 1998). As an outlook, we would like to remark that further analysis is still going on which should point out processes within the frontal areas (regional coherence duration).

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