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Intensive language learning and increases in rapid eye movement sleep: evidence of a performance factor

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Ten anglophone students taking a 6-week French immersion course were recorded in the sleep laboratory during 4 consecutive nights before the course, during the course and after the course. There was a positive and significant ($P < 0.05$) correlation between language learning efficiency and increases in the percentage of rapid eye movement (REM) sleep from pre-course to course periods. This observation suggests that learning performance may be an important factor in the relationship between information processing and REM sleep.

INTRODUCTION

It has long been proposed that rapid eye movement (REM) sleep is involved in some form or another in information processing and memory (i.e. Jouvet, 1965; Empson and Clarke, 1970). A leading notion formulated by Dewan (1970) and labelled the 'Programming Hypothesis', proposes that REM sleep is a process for setting up, or programming, and constantly revising functional structures in the brain, adjusting them to meet the current needs of the organism. Such a process would ensure consolidation of learning and prepare for the assimilation of new information. An alternative model was recently proposed by Crick and Mitchinson (1983), suggesting that it is during REM sleep that 'reverse learning' or the elimination of problematic information which otherwise compete with relevant material takes place. One prediction consistent with both models is that following intensive learning, organisms should exhibit an increased need for REM sleep.

For more than 15 years, a host of studies have tested this hypothesis and have been reviewed periodically along with other predictions relating REM sleep with information processing (i.e. Fishbein and Gutwein, 1977; McGrath and Cohen, 1978; Pearlman, 1979; Smith, 1985). While there has been overall support, one interesting observation has emerged. In animals, increases in REM sleep following learning tasks were related to learning efficiency (cf. Leconte et al., 1973) and not simply to the learning effort. Such a phenomenon was not, however, clearly established in humans, although observations along those lines have been made (Mandai et al., 1986; Verschoor and Holdstock, 1984). We have now gathered data from subjects involved in intensive language learn-

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ing which provide strong support for a relationship between learning efficiency and increases in REM sleep in humans.

METHODS

Subjects and design

Ten subjects, 6 males and 4 females within an age range from 18 to 28 years, participated in the experiment. They were registered in a French Immersion course at the University of Ottawa (described below). Their first language was English and their previous French language learning experience was limited to a secondary school level. They received $10 for each night spent in the laboratory.

French immersion course

Every summer, the University of Ottawa offers a 6-week intensive French immersion course to anglophone students. In addition to the courses, students attend evening activities conducted entirely in French. They spend weekdays in campus residence. Such an environment provides an ideal way to control learning conditions while maintaining subjects in a 'real-life' situation. French proficiency is measured by a test developed at the University of Ottawa. It has been used for 10 years and has proven to be a reliable and valid measure of competence in French. It is administered before the course and after the course thus providing an assessment of learning efficiency.

Design and procedure

The experiment was conducted over 3 summers. The first summer, 4 subjects were studied, the second summer 2, and the last 4 during the third summer. In each case, each subject spent a minimum of 4 consecutive nights in the laboratory on 3 separate occasions (6 subjects were recorded for two additional nights for dream collection). A baseline series was run within two weeks before the course. Subjects returned to the laboratory for Series 2 within the second or third week of the course. The last session was run within one month after the end of the course. In each series, the first two nights served as adaptation nights with data collection on nights three and four.

Electrophysiological measures

Standard electrophysiological sleep measures were recorded (Rechschaffen and Kales, 1968). EEG was recorded from sites C3 and C4 with a linked ear reference. EOG and EMG were recorded from bipolar montages. Electrode placement followed the standard 10–20 International system. The same sleep schedules were maintained from one series of recordings to another. The reliability of the sleep stage scoring was determined by calculating the percentage of agreement on 30-s sleep epochs from 6 full nights between our main judge and that of another 'blind' judge. Better than 81% agreement was achieved for all sleep parameters. For statistical analyses, data for nights 3 and 4 of each series were combined.

RESULTS AND DISCUSSION

Table I presents the distribution of sleep stage percentages in the three conditions. Analyses of variance revealed no difference for any of the sleep stages. However, when the learning performance of subjects was taken into account, a relationship between the percentage of REM sleep and learning efficiency was observed. Table II presents the detailed results of % REM and French proficiency test scores for each subject. An analysis of covariance using French improvement scores (post-course minus pre-course scores) revealed a significant increase in REM percentage from the

TABLE I

Distribution in mean percentages of sleep stages across conditions (nights 3 and 4 combined)

Sleep stage	*Pre-course*	*Course*	*Post-course*
Wake	2.15	1.38	4.19
Stage 1	7.26	7.49	6.80
Stage 2	45.99	48.13	45.17
Slow wave sleep (3 + 4)	24.51	22.71	23.87
REM sleep	19.67	22.31	22.22

TABLE II

Distribution in sequence of REM percentages before, during and after the immersion course along with scores on the French proficiency tests

Subjects	*Pre-course REM %*	*Pre-course French test*	*Course REM %*	*Post-course French test*	*Post-course REM %*
1	24.43	77	27.45	85	21.28
2	20.39	46	25.76	55	14.97
3	24.46	38	24.38	41	25.27
4	24.21	36	19.67	36	22.94
5	13.37	56	25.75	69	21.47
6	17.05	48	28.97	66	28.86
7	20.45	25	23.40	46	22.35
8	18.85	68	21.60	78	22.30
9	15.35	20	17.15	35	20.55
10	18.00	63	8.20	67	22.25

pre-course to the course period ($F = 6.83$, df = 1,8, $P < 0.03$).

This relationship is clearly illustrated in Fig. 1. This figure presents the distribution of REM percentages from pre-course to post-course for all of the subjects along with their percentages of improvement in French proficiency (subjects' graphs are presented in order of level of French proficiency improvement). It can be seen that only the last 3 subjects, with little (4% or less) or no improvement in French, did not show increases in REM % during the course. When only the 7 other subjects who showed improvements in French were considered, a repeated measures analysis of variance revealed a significant difference in REM % across conditions (means respectively, 18.6, 24.3, 21.7, $F_{2,12} = 4.35$, $P < 0.04$). Trend analyses revealed that the quadratic configuration (inverted U) was the most significant ($F_{2,12} = 6.13$, $P < 0.05$). In other words, efficient language learners exhibited an increase in REM % during the course and tended to return to baseline levels after the course. Finally, another way of expressing this relationship is the observation, for the total sample, of a significant Pearson product moment correlation coefficient ($r = 0.65$, df = 8, $P < 0.05$) between learning progress and increases in REM % from pre-course to course periods. However, the correlation between learning progress and changes in REM % from course to post-course was positive but not significant ($r = 0.28$). An examination of individual distributions (Fig. 1) suggests that this is due to the maintenance of high REM % or even further increases in some subjects (2, 3, 5).

Similar analyses performed on the other sleep stages did not reveal any significant trend. It appears then that the influence of intense language learning is restricted solely to REM sleep. Examination of individual records of the 7 subjects who experienced REM % increases suggests that stage 2 and/or slow wave sleep tended to be reduced with a greater vulnerability for the latter (4 subjects). These effects, however, were not significant.

These results are consistent with those obtained in studies with animals and are a first clear confirmation of a performance factor in the relationship between the amount of REM sleep and complex learning. It will be important to further explore this phenomenon and to determine whether our results are applicable to other types of human learning, where performance varies widely between subjects. Future research may also determine the influence of second language training on interhemispheric EEG during sleep. There is some controversy within the asymmetry literature as to the localization of second languages (Paradis, 1987). Furthermore one theory of interhemispheric relationships during sleep suggests that REM is associated with greater right activation while NREM sleep stages are said to involve left hemisphere activation (Goldstein et al., 1972;

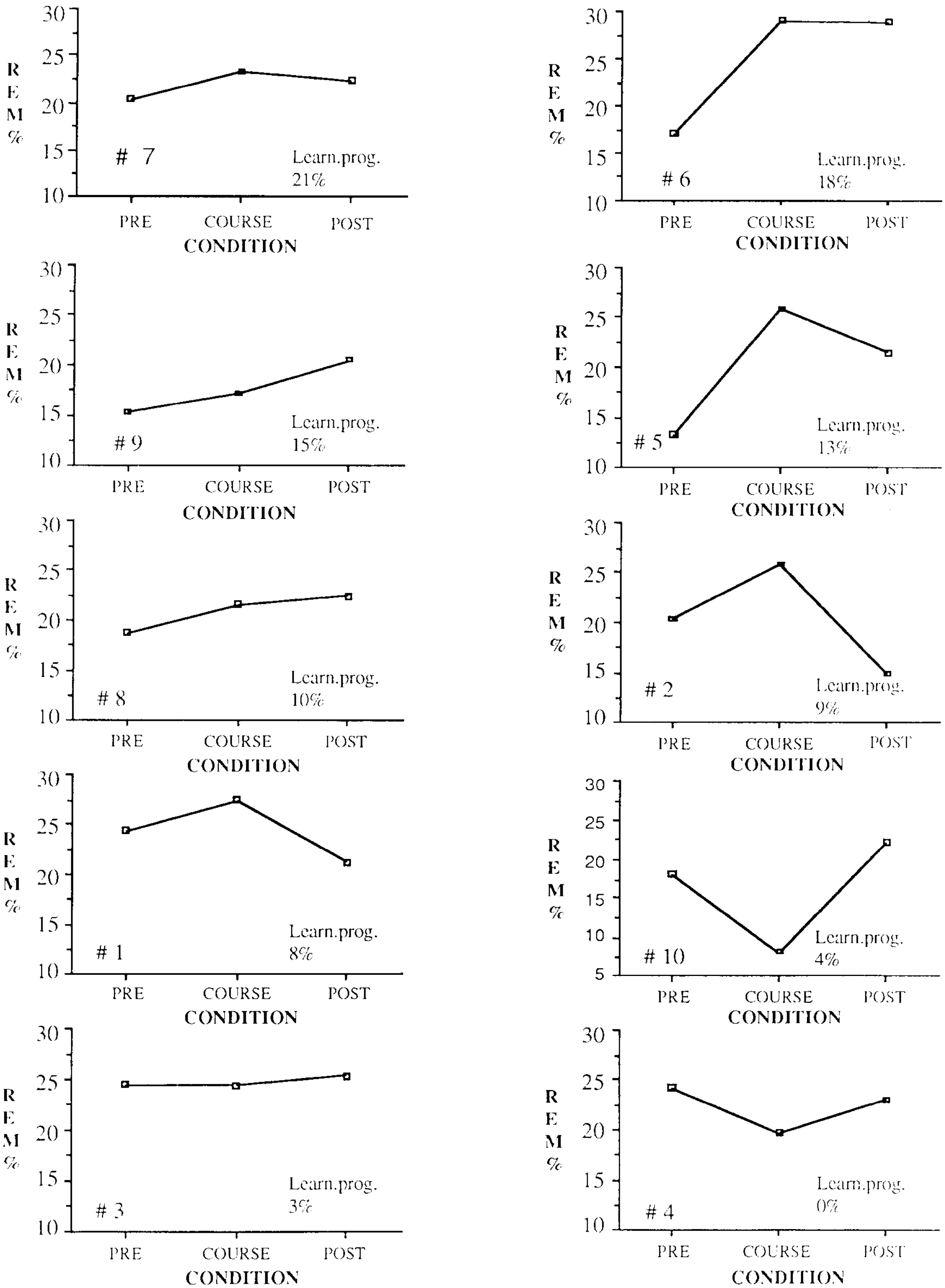

Fig. 1. Distribution of REM percentages for each subject, presented in order of learning progress.

Broughton, 1975). More recent studies have failed to support this theory (cf. Armitage et al., 1988). An evaluation of interhemispheric EEG changes during French immersion may resolve some of these controversies.

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