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Memory performance and area-specific self-regulation of slow cortical potentials: dual-task interference

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We examined the effect of area-specific feedback for slow potentials on sensorimotor and memory performance under single and dual-task conditions. Subjects observed a memory set for 400 ms and then determined 5 s later whether a target letter had been contained in the original presentation (Sternberg task). After one session of Sternberg-only training, feedback training was added for production of negative and positive slow potentials area-specifically at F_z , C_z or P_z during the 5-s interval separating the memory set and target probes. Addition of the feedback task resulted in an increase in Sternberg response latency and errors which was followed by gradual recovery over five dual-task sessions (recovery not complete for the error measure). Subjects successfully regulated their slow potentials, but only in an area-nonspecific fashion, even though area-specific control was observed in an earlier study under a feedback-only condition. Sternberg performance did not depend on whether slow potential negativity or positivity was produced. These findings indicate that competition between tasks was a more important determinant of performance than was modulation of dendritic polarization by feedback-induced slow potentials.

INTRODUCTION

In their recent discussion of neocortical architectures, Douglas and Martin (1990) observed that the apical dendrites of pyramidal cells present a puzzle. The electrotonic properties of these dendrites appear to be such that current injected into the distal portion has only a minimal effect on the pyramidal cell body. Because there is no phylogenetic evidence for elimination of the apical (plexiform) layer, it seems clear that some function is served, even though driving of pyramidal cells is unlikely. An alternative account of the functional role of the plexiform layer emphasizes that considerable calculation is carried out in the

dendritic arbour (Shepherd and Koch, 1990). The extent of these calculations and their influence on pyramidal cell firing may be regulated by the polarization of the plexiform layer, with such polarization being dependent on diencephalic and brain stem mechanisms situated more deeply (Birbaumer et al., 1990; Skinner, 1984).

Birbaumer et al. (1990) have summarized how instrumental conditioning of slow cortical potentials which are thought to reflect the polarization of the apical dendrites (Lutzenberger et al., 1987) can be used to test this hypothesis. Briefly, slow cortical potentials (SPs) are first brought under the control of a discriminative stimulus by giving subjects exteroceptive feedback for negative and positive shifts in these potentials. Once feedback regulation is established, 'probe' tasks of a perceptual, cognitive, or behavioral nature are superimposed on the self-regulated SPs to assess how

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information processing has changed (dual-task procedure). If negative SPs signify apical depolarization and enhanced computational readiness, probe-task performance should be facilitated when probe tasks are presented during periods of scalp negativity compared to presentation during scalp positivity, and vice versa. Several experiments have supported this prediction, showing enhancement of sensorimotor performance (Rockstroh et al. 1982), haptic discrimination (Rockstroh et al., 1990), decision accuracy (Lutzenberger et al. 1979), and computational skill (Lutzenberger et al., 1982) when probe tasks are presented during negative compared to positive self-regulated SPs. Similar results have been reported for probe tasks presented during spontaneously occurring negative or positive SP shifts in the EEG, rather than during feedback-regulated SP changes (Stamm, 1984).

The experiment reported in this article employed a new probe arrangement to test two ideas that lie at the basis of the dual task approach. The first idea assumes that different patterns of probe-task performance are likely to occur, depending on the functional role of particular neural networks that are facilitated by cortical negativity. To test this hypothesis, we employed a feedback procedure developed by Birbaumer et al. (1992) that was found to induce area-specific frontal and parietal regulation of slow potentials. Area-specific control of frontal and parietal SPs is of interest, because different behavioral activities are reported consequent on self-regulation at these sites. In particular, sensorimotor strategies involving movement or preparation for movement are described when subjects regulate their frontal SPs area-specifically, whereas verbal reports of a nonmotoric, attentional nature are obtained when subjects regulate their parietal SPs area-specifically (Birbaumer et al., 1992). In the present study, we superimposed a probe task requiring perceptual analysis, memory retrieval and response production while subjects self-regulated their SPs at frontal and parietal sites. If different functional networks are facilitated by depolarization of apical dendrites in these regions, different patterns of probe-task performance were expected depending on the topography of the in-

duced SP shift (in particular, modulation of sensorimotor response time by SPs regulated frontally, and of perceptual/memory accuracy by SPs regulated parietally).

The second question addressed by the current study concerned how modulation of probe-task performance by feedback-induced SPs is to be interpreted. In previous dual-task studies of SPs, it has been customary to compare probe-task performance between epochs of self-induced SP negativity and positivity when testing for facilitatory effects. Because the demands of feedback processing are the same for these conditions, differences in task performance between them are presumed to relate to the computational efficiency of dendritic arbours whose polarization has been modified (Birbaumer et al., 1990). However, dual task procedures have more typically been depicted as exercises in doing two things at once (Heuer and Wing, 1984). Trade-offs are expected between tasks, to the extent that attention or other limited resources (for example, access to a common effector) are required for each. This account applied to dual-task studies of SPs suggests that, contrary to being facilitated by induced cortical negativity, probe-task performance may actually be impaired relative to single task conditions. Differences in probe-task performance may nevertheless materialize between SP negativity and positivity, depending on what subjects must do to produce SP negativity and positivity and on how their strategies for these SP responses interact with the cognitive and motoric requirements of the probe procedure (Allport, 1980; Roberts et al., 1989). In the present study we evaluated these two accounts of task relations by comparing performance when the probe procedure was given alone (single-task condition) with that obtained when the probe procedure was given during the feedback requirement (dual-task condition). Impairment of probe performance under the dual task condition would give reason to consider whether the differential effects of SP negativity and positivity on probe-task performance might be understood in terms of differential interference of the subject's feedback strategies with the probe task, rather than in terms of a facilitation of probe performance by activation of

dendritic arbours consequent on feedback-induced slow potentials.

METHODS

Subjects

30 students, 18 males and 12 females aged 20–35 years, were randomly assigned to three experimental groups, with the restriction that 6 male and 4 female subjects had to appear in each condition. The three groups differed only with regard to whether feedback was given for area-specific SPs recorded at the frontal midline (F_z), parietal midline (P_z) or the vertex (C_z). The vertex group was included to maintain consistency with an earlier study (Birbaumer et al., 1992) in which C_z feedback provided a further reference point for assessment of area-specific SP regulation. Subjects were paid DM 20 (about \$12 US) per session plus bonus money of approx. DM 10 per session, according to their success on the feedback task.

Apparatus and physiological recordings

The electroencephalogram (EEG) was recorded monopolarly at F_{pz} , F_z , C_z , P_z and O_z following the 10/20 system. Electrodes affixed to the ear lobes, second vertebra and right clavicle served as non-cephalic reference points. The skin at each site was prepared by cleaning with alcohol and applying an abrasive paste (Omniprep). Non-polarizing Ag/AgCl electrodes (Zack) were used. The EEG was amplified by a Nihon-Kohden amplifier specially manufactured to have a time constant of 10 s. Signals were sampled at 100 Hz. Amplifier output was filtered by the method of Elbert and Rockstroh (1980) to give the DC component. We will refer to the filtered EEG channels as SPs.

Electro-oculograms (EOGs) consequent on vertical (VEOG) and lateral (LEOG) eye movements were also recorded at 100 Hz. Ag/AgCl electrodes were affixed 1 cm above and below the left eye and at the outer canthi. These measurements were used to prevent contamination of SPs by eye movement artifact (see below).

A network of computers (PDP 11/73 and 8/e) was used to generate the experimental stimuli, implement the feedback contingencies, and store digitized physiological data.

Feedback task

Continuous visual feedback was provided for SP shifts over feedback intervals of 5 s duration. The feedback stimulus was the outline of a rocket ship that appeared in the center of a 30×40 cm television screen situated 2 m in front of the subject at eye level. The rocket moved back and forth in a horizontal plane through a gap formed by an upper and lower vertical bar, as shown in the upper panel of Fig. 1. Trials were designated by presentation of the rocket in the central gap, pointing either to the left or to the right. The subject's task was to move the rocket out of the gap in the designated direction. For half of the subjects rightward movements were produced by SP negativity and leftward movements by SP positivity, whereas for the remaining subjects this assignment was reversed. Excursions of the rocket in a direction opposite to the required one (error feedback) were discouraged by the instructions that subjects received. Subjects were not informed of the responses that were trained, but relied instead on feedback as a guide to success. Subjects also received bonus money for performing successfully. Whenever the obtained SP shift exceeded either $-6 \mu\text{V}$ or $+6 \mu\text{V}$ from baseline, the outline of the rocket became filled, signalling that the subject had earned or lost a 'win' point worth DM 2 (depending on whether the rocket was on the success or failure side of the starting gap).

In order to avoid the evoked potential elicited by visual stimulation, the position of the rocket remained fixed at the central gap for the first second of each feedback trial. For the remainder of the trial (seconds 2–6) movements of the rocket were a linear function of the integrated EEG referred to the mean of a 4-s pretrial baseline (SPs). In order to increase the likelihood of area-specific regulation in each feedback group (frontal, central and parietal), the reference point for measurement of SPs included not only the ear lobe and noncephalic sites, but also scalp loca-

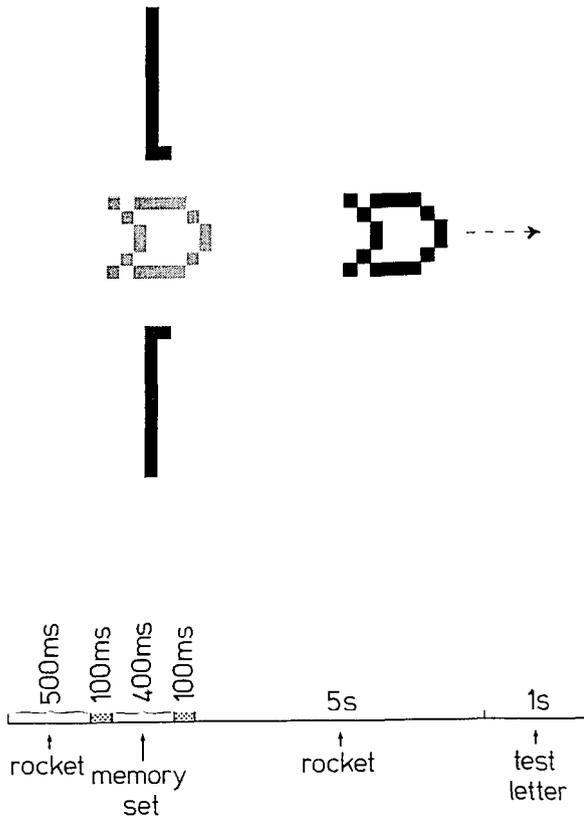


Fig. 1. Feedback (upper panel) and Sternberg (lower panel) tasks. The upper panel shows a feedback display requiring right-ward movements of the feedback cursor (rocket ship). The vertical bars forming a gap (the starting location of the rocket) were presented in the center of the television screen. The lower panel shows the sequence of events within trials on which the Sternberg task was performed. The rocket disappeared at its starting location when the memory set was presented (disappearance symbolized by a faded image in the upper panel of this figure).

tions adjacent to the site at which specificity was sought (procedure of Birbaumer et al., 1992). Thus, in the frontal group SPs recorded at F_z were referred to an average of recordings taken at F_{pz} , C_z , P_z , O_z , the linked ear lobes and the non-cephalic electrodes. Similarly, in the central group feedback was given for the C_z recording referenced to the average of all remaining sites, and in the parietal group for the P_z recording similarly referenced. Reference sites were linked by digital averaging and not by hard-wired contact. A time-out contingency arrested excursions

of the rocket whenever VEOGs of the same polarity as the required SP shifts were detected (for a detailed description of artifact control procedures, see Elbert et al., 1985). Offset voltages were not included in the algorithm used to calculate SP feedback in any group (after Birbaumer et al., 1992).

Probe task

The probe task was designed to allow 'parietal' modulation of attentional functions relating to perceptual encoding and memory retrieval (response accuracy) and 'frontal' modulation of response decision and motor preparation (response latency). A Sternberg-type memory task was chosen because it provided accuracy and latency measures in the same procedure. If perceptual encoding and memory retrieval are modulated by SP polarities induced parietally (Birbaumer et al., 1992; Rösler and Heil, 1991), recognition memory for a probe stimulus should covary with SP negativity/positivity in the group receiving feedback from P_z^* . On the other hand, if decision processes and motor responding are modulated by SP polarities induced frontally, response latency should vary between SP negativity/positivity in the group given feedback at the F_z electrode. The probe task was also performed by subjects receiving feedback at C_z , which provided a further test of whether task performance depended on the topography of area-specific SP modulation.

The Sternberg task was performed alone in the first session of the experiment (single-task phase). Even though SP feedback was not given during this phase, a moving rocket was included in the display so as to equate visual displays between the single and dual-task phases. The sequence of events comprising the Sternberg procedure in this session is depicted in the lower panel of Fig. 1. At

* The hypothesis that depolarization of apical dendrites favors processing in a cortical projection area suggests that parietal memory functions will be facilitated by negativity in parietal cortex. However, Rösler and Heil (1991) and Rockstroh and Elbert (1990) have suggested that memory performance may be associated with positivity in parietal networks. Feedback regulation of parietal SPs provides a test of this question.

the start of the trial a rocketship appeared for 500 ms in the middle of the TV screen, between the two vertical bars that marked the starting position. Then, following a break of 100 ms during which the TV-screen remained white, a memory set comprising either two or four letters appeared for 400 ms at the very same location at which the rocket had disappeared (the latter event depicted by the faded image in the upper panel of Fig. 1). A different memory set was selected randomly from a predetermined list on each trial, but the sets on this list remained constant over training. After another break of 100 ms the rocket reappeared for 5 s and moved to the left or right according to a pre-recorded algorithm (these excursions approximating those produced by subjects who regulated their SPs area-specifically in the study of Birbaumer et al., 1992). Subsequent to the termination of this 5 s simulated feedback interval, a probe letter was presented for 1 s at the center of the location where the rocket had disappeared. Subjects were asked to evaluate whether or not the probe stimulus was member of the memory set. Subjects pressed a button with the left hand if the probe letter belonged to the memory set, or with the right hand if it did not. Thus, each trial comprised a baseline interval of 4 s, presentation of the rocket (0.5 s) and memory set (0.4 s), a 5-s feedback interval (simulated feedback in the Sternberg-only session), and a 1-s probe letter (11.1 s overall, including two 100-ms gaps before and after the memory set). Trials were separated by intertrial intervals varying between 4 and 14 s.

Experimental sessions

Each subject participated in six sessions scheduled on three consecutive days. The two daily sessions were separated by a short break of about 10 min. Each session consisted of 80 trials. In the first session (single-task phase), subjects were informed that excursions of the rocket were unrelated to their behavior and that they should concentrate on the Sternberg procedure. In subsequent sessions, feedback was made conditional on SPs and subjects were instructed to perform both tasks simultaneously (dual-task phase).

Data reduction

Self-regulation of SPs was assessed by subtracting the mean SP observed during the last second of the pretrial period from the mean observed during the 5-s feedback interval (after Birbaumer et al., 1992). In order to be sure that SP modulation was achieved at the feedback electrode and not at one of the reference sites, these 'change scores' were based on SPs referenced to linked ears only*. Change scores were averaged separately for negativity and positivity trials at each recording site. Trials on which the DC shift exceeded 100 μV in one of the EEG channels or 30 μV in either of the EOG channels were excluded from this analysis, and from the analysis of all other response measures. It was often convenient to summarize the effect of feedback training by subtracting the SP shift obtained on positivity trials from that obtained on negativity trials. Measures computed this way are referred to as 'bidirectional'.

The plan for statistical analyses was adopted from the study of Birbaumer et al. (1992), which used feedback algorithms similar those of the present study. Statistical tests were two-tailed. Greenhouse-Geisser corrections (ϵ) are reported where sphericity violations were found, and significance levels were adjusted accordingly (adjusted levels reported herein).

RESULTS

We considered (a), performance on the Sternberg task (Session 1, Sternberg-only); (b), feedback regulation of SPs (Sessions 2–5) and (c),

* The algorithm used to compute exteroceptive feedback in this study (SPs at the feedback site minus the weighted average of 8 reference sites) favored area-specific manipulation of SPs at the feedback electrode over alternative manipulation of SPs at one or more reference sites, because SP shifts at the feedback electrode (the first term in the equation, weighted 1.0) had greater influence on the feedback calculation than did any reference site considered singly (eight reference sites used, each weighted 1/8 in determination of the reference potential). The SP effects reported herein did not differ when compared between the two reference calculations.

how the two tasks influenced one another (Sessions 2–5).

Sternberg task

Fig. 2 (upper panel) shows how electrocortical activity was affected by the Sternberg task in the first session of the experiment, during which there was no feedback requirement. Presentation of the memory set elicited a positive potential in the EEG (a P300 wave) at all midsagittal sites (this is the second detectable P300 shown in Fig. 2, commencing at about 0.5 s; the first P300 was in response to the appearance of the rocket). A third P300 wave occurred when the probe letter was displayed at 6.1 s. These waves tended to be largest in the parietal trace, which is typical of P300s elicited by task stimuli (Squires et al., 1975). The effect of recording site (F_z , C_z , P_z) reached

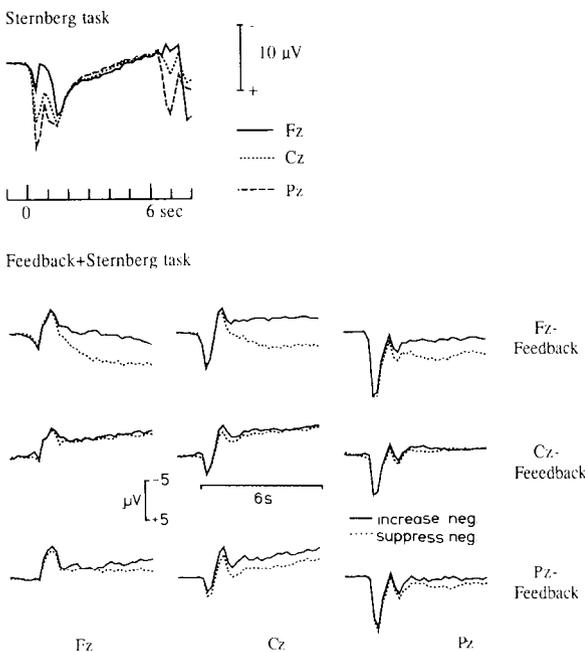


Fig. 2. Top panel: Slow potentials elicited by presentation of the Sternberg task during the Sternberg-only session. Bottom panel: Slow potentials recorded during the last two dual-task sessions (Feedback plus Sternberg procedures). Slow potentials recorded from F_z , C_z and P_z (abscissa) are shown for groups receiving feedback at the different midsagittal sites (ordinate). Traces are truncated at the end of the feedback interval (6.1 s) to avoid the P300 elicited by presentation of letter probes (these P300s are shown in the top panel).

significance for the P300 elicited by set presentation, $F(2,54) = 10.6$, $p < 0.01$, but not for the other P300s. Electrocortical responses did not differ significantly as a function of set size (two versus four letters) in the Sternberg-alone session or when all sessions were combined.

However, response latency and errors were affected by set size in the Sternberg-alone session and thereafter. Response latencies averaged 983 ms and 1128 ms for the two and four letter sets, respectively, $F(1,27) = 46.6$, $p < 0.001$; error rates were 7.9% and 13.4% respectively, $F(1,27) = 13.8$, $p < 0.001$ (sessions combined). These findings are consistent with the larger memory burden induced by the four-letter set.

Feedback regulation of slow potentials

After the Sternberg-only session, subjects were required to self-regulate their SPs area-specifically. Differentiation of negativity and positivity trials is shown in the lower panel of Fig. 2, for the F_z , C_z and P_z groups at each recording site (last two dual-task sessions, referenced to linked ears). Subjects receiving feedback at F_z differed bidirectionally at F_z , $t(9) = 3.0$, $p < 0.05$, but also at C_z , $t(9) = 3.4$, $p < 0.01$ and P_z , $t(9) = 2.5$, $p < 0.05$, with no difference among these midline locations. Bidirectional differences were not significant at any site in the remaining groups which received central or parietal feedback. This picture was confirmed by a main effect of Negativity/Positivity, $F(1,27) = 14.9$, $p < 0.001$, and an interaction Groups \times Negativity/Positivity, $F(2,27) = 4.1$, $p < 0.05$, the latter effect reflecting differentiation of SPs in the frontal compared to the other groups. Main effects and interactions attributable to Electrode Site (F_{pz} , F_z , C_z , P_z , O_z) and Set Size were not significant. These findings show that feedback regulation of SPs was achieved, but mainly in the frontal group, and there was no area-specific effect.

Relation of feedback and Sternberg performance

Fig. 3 shows the effect, on Sternberg performance, of introducing the feedback procedure, and of continued training in the dual-task condition. Introduction of the feedback task resulted in an increase in response latency on the Sternberg

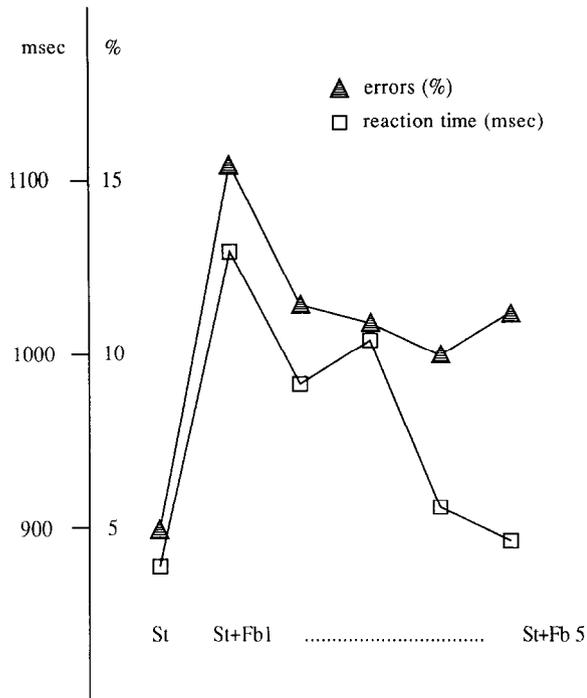


Fig. 3. Response latency and errors on the Sternberg task (all trials) during the Sternberg-only session (St) and subsequent dual-task sessions (St + Fb).

procedure in the first dual-task session (St + Fb1) and was followed by a gradual recovery thereafter. A main effect was found for Sessions in the latency measure, $F(5,135) = 7.6$, $p < 0.001$, $\epsilon = 0.47$ and also for error rates which followed a similar course, $F(5,135) = 11.7$, $p < 0.001$, $\epsilon = 0.71$. Recovery was more apparent in response latency than in errors over the course of dual-task training. Response latencies did not differ when contrasted directly between the first and last sessions ($t < 1$), but an effect on errors was evident, $t(29) = 3.69$, $p < 0.001$. Neither measure showed improved performance in the dual compared to single task condition at the end of training.

Although introduction of the feedback task impeded Sternberg latency and errors, these measures may nevertheless have depended on whether SP negativity or positivity was induced by the feedback contingency. To evaluate this possibility, analyses of variance were applied to the response latency and error data collapsed over

the last two dual-task sessions. No main effects or interactions involving negativity/positivity were found for Sternberg latency or errors, even though differentiation of SPs was obtained in the combined sample and in the frontal group in particular for these sessions (Fig. 2). Bidirectional analysis of the latency and error data for the feedback groups separately corroborated this picture. Although no bidirectional comparison reached significance, the largest polarity effects on Sternberg latency and errors were obtained in the frontal group. Response latency, $t(9) = 2.16$, $p < 0.06$, and error rates, $t(9) = 1.50$, $p < 0.17$, tended to be larger on negativity trials than on positivity trials in this condition.

The preceding results suggest that SP polarity had little effect on Sternberg performance, and

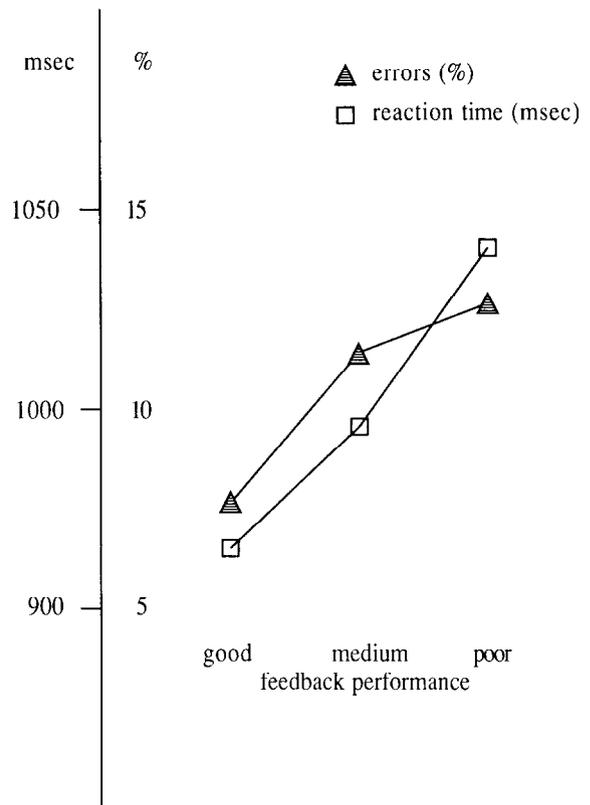


Fig. 4. Within-subject relation between Sternberg performance (response latency and errors) and slow potential self-regulation. Data are from the last two dual-task sessions (negativity and positivity trials combined).

that the feedback and Sternberg procedures were better characterized as separate competing tasks. If this is so, then superior performance on one task would have been expected to accompany inferior performance on the other as the procedures competed for access to limited capacity mechanisms. To assess task relations at the within-subject level, we calculated Sternberg response latencies and errors separately for trials with good, medium, or poor performance on the feedback task (feedback groups combined). Good performance was defined as a shift in SPs exceeding $6 \mu\text{V}$ in the direction of training (positivity or negativity), and poor performance as a shift exceeding $6 \mu\text{V}$ in a direction opposite to training (medium performance everything in between). The results are given in Fig. 4 collapsed over the last two dual-task sessions. Contrary to expectation, success at SP production was accompanied within subjects by improved, not inferior, Sternberg performance. This was true of response latency, $F(2,54) = 7.3$, $p < 0.01$, $\epsilon = 0.73$, as well as error rates, $F(2,54) = 12.1$, $p < 0.001$, $\epsilon = 0.99$. Furthermore, this result did not depend on whether good performance meant that SP negativity or positivity was achieved. Main effects and interactions attributable to Negativity/Positivity were not significant for either the reaction time or error rate data (negativity and positivity trials combined in Fig. 4).

DISCUSSION

Calculations based on biophysical models of the cranium have suggested that polarization of the plexiform layer is a major source of the scalp-recorded EEG (Lutzenberger et al., 1987; Braun et al., 1990). Current source density measurements support this picture for scalp potentials with long time constants such as the slow negative wave (Mitzdorf, 1985). These findings have formed the basis of a research strategy in which the function of neocortical dendritic arbours is investigated by applying probe tasks when the polarization of the plexiform layer is altered by feedback training for SPs (Birbaumer et al., 1990). The present study asked (a), whether re-

sponse times and memory performance are affected differently by SP shifts induced frontally and parietally in an area-specific fashion, and (b), whether modulation of these aspects of probe performance by feedback-induced SPs can be attributed to facilitation of performance by SP negativity, or alternatively, whether they appear to be due to interference between feedback and probe procedures when these procedures compete for access to limited capacity mechanisms (Heuer and Wing, 1984; Roberts et al., 1989).

Our findings supported the latter interpretation for the current training arrangement, by documenting two types of task interference. First, we found that subjects performed more poorly on the Sternberg procedure when the feedback requirement was imposed than when the Sternberg task was given alone. When feedback was present, subjects responded more slowly to Sternberg probes and made more errors (Fig. 3), indicating competition between the Sternberg and feedback procedures for shared mechanisms. This competition was not short lived but persisted during the dual-task phase, especially in the error measure.

The second type of interference concerned performance on the area-specific feedback procedure itself. Although our subjects regulated their SPs differently on negativity and positivity trials, they were unable to do so in an area-specific fashion. Instead, area non-specific regulation of SPs was observed, and mainly in the frontal group. This result differs from an earlier study in which area-specific regulation was achieved at frontal, central and parietal sites when area-specific feedback was given as a single task (Birbaumer et al., 1992). Hence it appears that, like Sternberg performance, area-specific regulation of SPs is disrupted by a dual-task requirement. In accordance with this conclusion, Birbaumer et al. (1992) found impairment of area-specific SP regulation when memory and perceptual tasks were added to the feedback procedure after three sessions of feedback-only training. In the present study we gave subjects prior practice at the Sternberg procedure and extended dual-task training to five sessions in an unsuccessful attempt to avoid interference attributable to task unfamiliarity. The presence of

interference and its prominence in early in dual-task phase corroborates evidence from the analysis of verbal reports that feedback regulation is attention demanding (Roberts et al., 1989; Williams and Roberts, 1988).

It should be noted that the presence of interference between the feedback and Sternberg procedures does not preclude the additional possibility that Sternberg performance may have been modulated by the polarity of feedback-induced SPs. This possibility exists because two tasks can interact differently with respect to their constituent components (Allport, 1980). On the basis of previous evidence linking frontal SP negativity with sensorimotor readiness (Rockstroh et al. 1982, 1990), we predicted faster response latencies during SP negativity in our frontal group. However, latency was not facilitated by SP negativity in this group, even though differentiation of SP negativity/positivity was obtained. On the contrary, subjects in the frontal group tended to respond more quickly ($p < 0.06$) and make fewer errors ($p < 0.17$) when SP positivity was required. These nonsignificant trends appear to be explicable in terms of task interference. Because passive strategies involving sensorimotor and emotional quiescence are used to achieve SP positivity (Birbaumer et al., 1992; Roberts et al., 1989), subjects may have been able to make a greater investment in the Sternberg procedure when this polarity of SP shift was signalled. Under this condition the effect of set size that was seen during the Sternberg-only phase ($p < 0.001$) began to materialize, so that latency and errors were affected jointly.

These findings support a general principle that attributes transfer effects during SP self-regulation to an interaction of the performance requirements of the feedback procedure with the performance requirements of the probe task that is applied (Allport, 1980; Roberts et al., 1989). However, there is reason to suggest that modulation of secondary task performance by fluctuations in the polarization of apical dendrites can occur in other task arrangements (Rockstroh and Elbert, 1990). Stamm (1984) has shown that reaction time to probe stimuli is speeded if probes are presented during spontaneously occurring nega-

tive, rather than positive SPs in the EEG. Competition for resources is unlikely to be a factor under these circumstances, because subjects are not actively processing information related to a second performance. However, even when a second task is present, transfer effects appear to involve more than task interference. For example, signal detection is known to relate nonmonotonically to feedback-induced slow negativity (Lutzenberger et al., 1979). Because maximum detection is obtained when SPs are within an intermediate range (deterioration at both extremes), explanation in terms of task interference alone will not work (monotonic negative transfer expected in this case). Finally, it should be noted that although feedback negativities induced at frontal and central sites are associated with sensorimotor readiness (Birbaumer et al., 1992; Roberts et al., 1989), these negativities also appear to modulate nonmotor functions such as vigilance and mental computation (Lutzenberger et al., 1979, 1982). Whether these performances are facilitated over single task baselines is not known and warrants further study.

In one respect, the present findings did not appear to point to competition for shared resources by the Sternberg and feedback tasks. Although introduction of the feedback task in the second session was severely detrimental to Sternberg latencies and errors, we did not find a trade-off between the feedback and Sternberg procedures when we analyzed task relations at the within-subject level. Instead, superior performance tended to go together on the two tasks, regardless of whether SP negativity or positivity was required (Fig. 4). The solution to this puzzle may be that subjects were able to shift their attention between the two tasks within the course of feedback trials (Heuer and Wing, 1984). When excursions of the feedback rocket indicated that a feedback trial had been solved, subjects were free to increase their investment in the Sternberg procedure; conversely, when feedback errors occurred, attention may have been drawn away from the Sternberg problem. Hence, the relationship of Fig. 4 does not conflict with the main finding of our study, which is that dual-task competition was a more important determinant of

task relations than was the polarity of feedback-induced SP shifts.

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