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THE EVENT RELATED BRAIN POTENTIAL AS AN INDEX OF INFORMATION PROCESSING, COGNITIVE ACTIVITY, AND SKILL ACQUISITION: A PROGRAM OF BASIC RESEARCH

ANNUAL PROGRESS REPORT

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report describes research partially or entirely conducted on the contract during the fiscal year 1981. It describes experiments and developments related to six basic categories of research on the event-related brain potential, performance, and cognition: (1) Tracking, attention, and workload; (2) automation, skill learning, memory, and the "depth" of information processing; (3) individual differences; (4) mental chronometry; (5) other components of the ERP than P300; and (6) methodologies and analytical techniques.

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AFOSR ANNUAL PROGRESS REPORT

We report below the progress made in 1981 under AFOSR Contract #RFR F49620-81-R-0036: The Event-Related Brain Potential as an Index of Information Processing, Cognitive Activity and Skill Acquisition. The report describes studies completed during the project period, research that is in progress, and experiments in their initial stages. The report is divided into six broad categories; the first four focusing primarily on the P300 component: 1. Tracking and Workload, 2. Attention Allocation, and Learning and Memory, 3. Individual Differences in Cognitive Performance, 4. P300 and Processing Latency, 5. Other Components, and 6. Analytical Techniques. Within each category we include investigations at all phases of completion. When investigations are identical to those described in the original research proposal, the numbers given in that proposal will be presented in parentheses. Some studies appropriately belong in more than one category. In such cases, the appropriate alternative category memberships will also be specified.

1. Tracking and Workload

This research continues and extends our previous inquiries into the relation between P300 amplitude, processing resource demands and task difficulty. Of primary interest is the tracking, or manual control, task. In Experiment 1.1 we explore the possibilities of assessing tracking workload, ERPs elicited by events associated with, primary, rather than secondary, tasks. In Experiments 1.2.1 and 1.2.2, we use P300 to evaluate the dynamic aspects of resource allocation between higher order tracking and the probe task. In the process we gain insight into the processing characteristics of higher order manual control. Experiment 1.3 develops and validates an innovative technique for training operators to control second order systems and employs the P300 as a workload index. In the process we develop an algorithm for quantifying the development of the operator's "internal model" of the system dynamics. Experiment 1.4 extends our previous examination of the auditory display in manual control. Finally, Experiment 1.5 extends our workload research beyond that of manual control to the domain of a more complex process monitoring task such as that confronting the nuclear power monitor.

1.1 Workload Measures Embedded Within the Primary Task

(3.1.1 and 4.1.1 of original proposal, reported in Kramer, Wickens, Vanasse, Heffley and Donchin, 1981). In the secondary task "probe" measures of workload, a secondary task is imposed on the subject. Performance, and ERPs, associated with the secondary task are used to assess the "residual" resources not allocated to the primary task. In our research, P300 elicited by the secondary task probe stimuli is recorded, and found to be directly related to residual capacity in the peripheral domain and therefore inversely related to primary task workload. One of the limitations of this technique is that the secondary task may potentially disrupt primary task performance. In the present experiment we hypothesized that as primary task workload is increased, thereby demanding more resources, P300s elicited by events intrinsic to the primary task should reveal this increase by showing a direct relation to primary task workload, rather than the inverse relation shown by secondary task probes.

In our experimental evaluation of this hypothesis, subjects performed a step tracking task of varying levels of difficulty. Difficulty was manipulated by (a) increasing the order of the control dynamics, (b) decreasing the spatial predictability of the series of step changes that were to be tracked. The "steps" constituted events, associated with the primary task, which could elicit ERPs. Primary task performance and subjective ratings both indicated difficulty to increase across these manipulations. When we employed secondary task auditory probes to measure residual capacity, our P300 workload index indicated as well that workload increased. In the critical test of our hypothesis we observed that P300s elicited by the step changes increased in amplitude with increasing primary task difficulty, as more resources were allocated to the more demanding task. This was true whether or not subjects were required to count the steps. Thus, the hypothesis was confirmed. The reversed effect of workload on primary and secondary task P300s is shown in Figure 1.1.1, depicting the raw ERP waveforms, and in Figure 1.1.2, presenting the quantified measure. Figure 1.1.3 shows the joint effect of our difficulty manipulations and probe conditions on tracking performance and subjective workload. Both measures indicate that our manipulations were successful.

A third condition required subjects to count events that were in the same modality (visual) as the primary task, but unlike the steps were not task related (flashes) of a horizontal bar. P300s to these probes were <u>unaffected</u> by task difficulty suggesting that this condition possesses a degree of shared attributes with the primary task that is intermediate between the "competition" with the secondary task probes and the "cooperation" with the probes intrinsic to the primary task. The finding

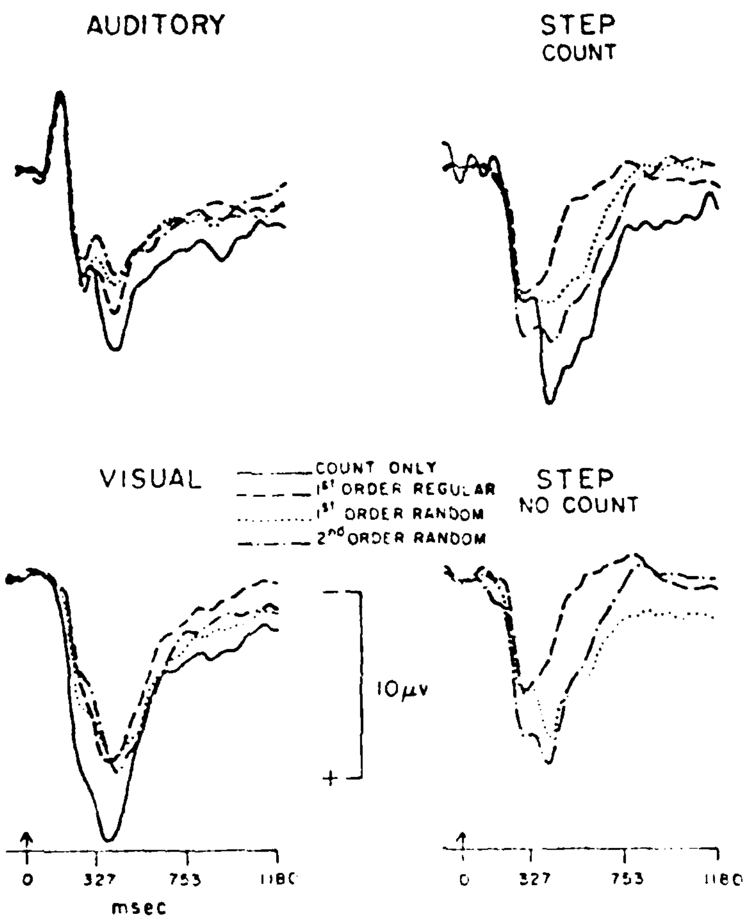

Figure 1.1.1

ERPs elicited in the control (no tracking) and three difficulty conditions. Each set of waveforms corresponds to a different probe condition.

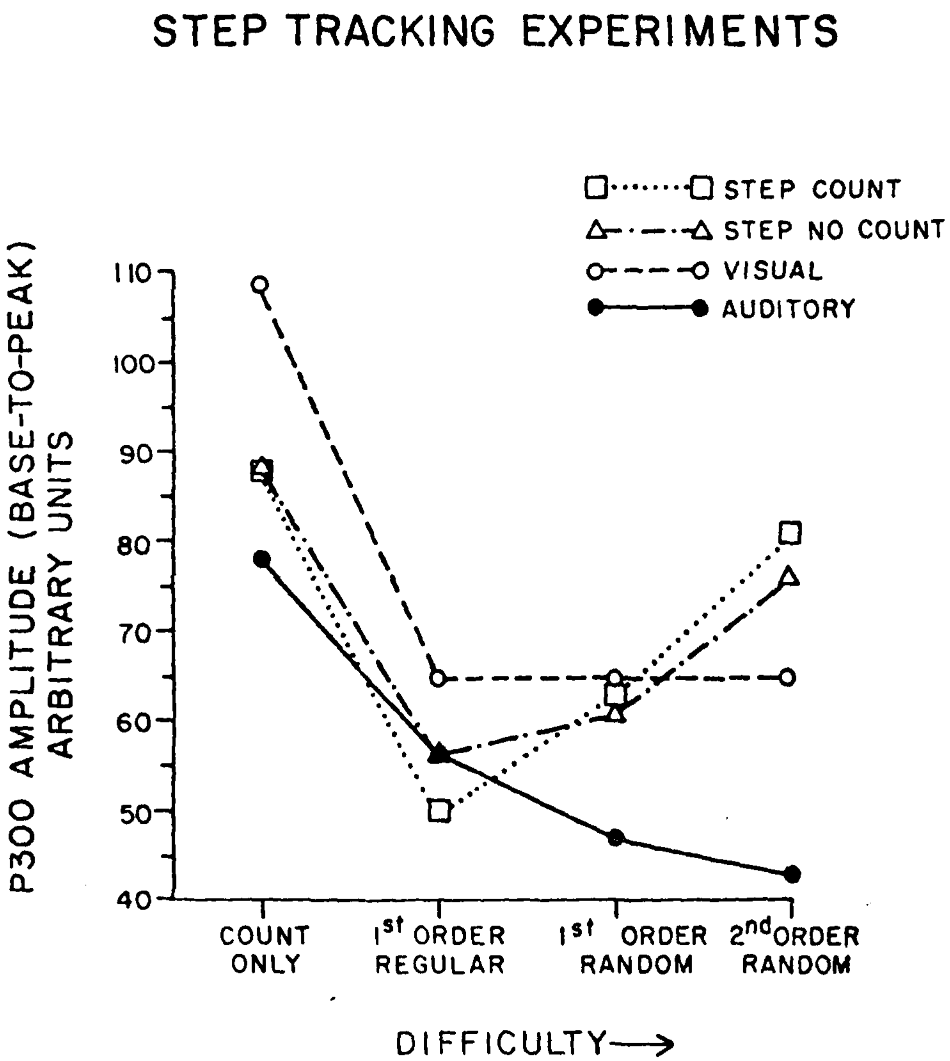

Figure 1.1.2

P300 amplitude as a function of step tracking difficulty and probe format.

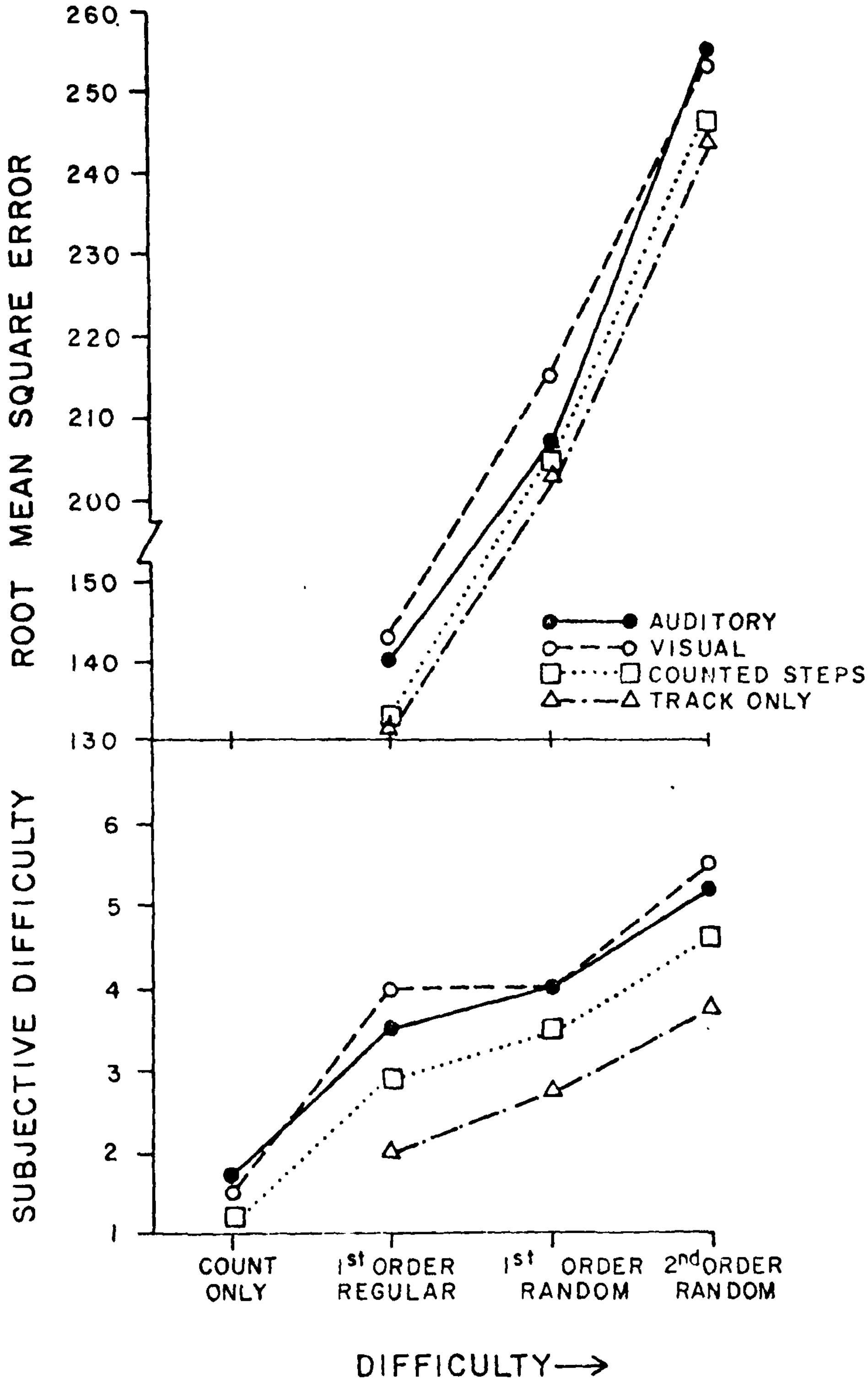

Figure 1.1.3

Tracking performance and subjective difficulty in the probe and difficulty conditions.

that irrelevant visual probes are insensitive to primary task workload manipulation has now been demonstrated in a number of investigations in our laboratory, and will be the subject of further inquiry. The finding of the present study that intrinsic probes can reveal workload effects with little or no cost has important theoretical and practical implications. The fact that the amplitude of P300 elicited by the secondary task probes decreases with primary task difficulty while P300 associated with the primary task increases with task difficulty, is of considerable theoretical importance because it is consistent with the model that underlies much of our work in this area. The resource allocation model implies a reciprocity between the primary and secondary tasks. As resources are consumed by one they are less available to the other. Until now we did not have a direct demonstration of this reciprocity.

1.2 Information Extracted During Higher Order Manual Control

(3.1.2, reported in Wickens, Gill, Kramer, Ross and Donchin, 1981). Our previous investigations, and that reported above suggest that the control of second order systems consume resources to which P300 is sensitive (e.g., perceptual/central). P300 to secondary task probes is consistently lower in second as opposed to first order tracking. The precise source of this increased load is uncertain however. Two hypotheses are plausible. The perceptual hypothesis asserts that, since higher order control requires the perception of higher derivatives of the error signal, the greater resource cost is reflected at the periods in which error acceleration is high, or at a more general level, when the momentary perceptual state of the system imposes increased perceptual demands. The central hypothesis argues that the operator must maintain a more complex "internal model" of the second order system (requiring two rather than one state variable to be characterized) and it is this increased cognitive complexity that is responsible for the higher load. The primary difference between these hypotheses, is that the perceptual hypothesis predicts that the resources demanded by tracking (and therefore available to the probe task) will vary from movement to movement, depending upon the momentary "state" (error and its derivatives) of the tracking error. The central hypothesis predicts a constant demand over time, as the complex model is "activated" at the outset, and maintained throughout the trial.

In Experiment 1.2.1 ERPs were selectively averaged according to the state of the error signal; whether its acceleration, velocity and position was high or low. Along none of these three dimensions did we find P300 to be reliably different between the high and low values. A second analysis examined P300 as a function of the momentary "urgency" (need for control) of the tracking system as defined by the combination of signal derivatives. Again, no differences were observed.

In Experiment 1.2.2, using a different group of subjects a more sophisticated analysis was undertaken to ascertain each individual subjects' "switching line" in the state-space representation of error by error velocity (Figure 1.2.2.1). The switching line reflects, in essence the linear combination of these two variables at which a subject decides that a control response must be implemented to nullify the error. This decision point is assumed to reflect a movement of heightened demand. Once again our selective averaging of P300 by regions in this state space near and far from the switching line failed to reveal any hint of P300 differences. Our

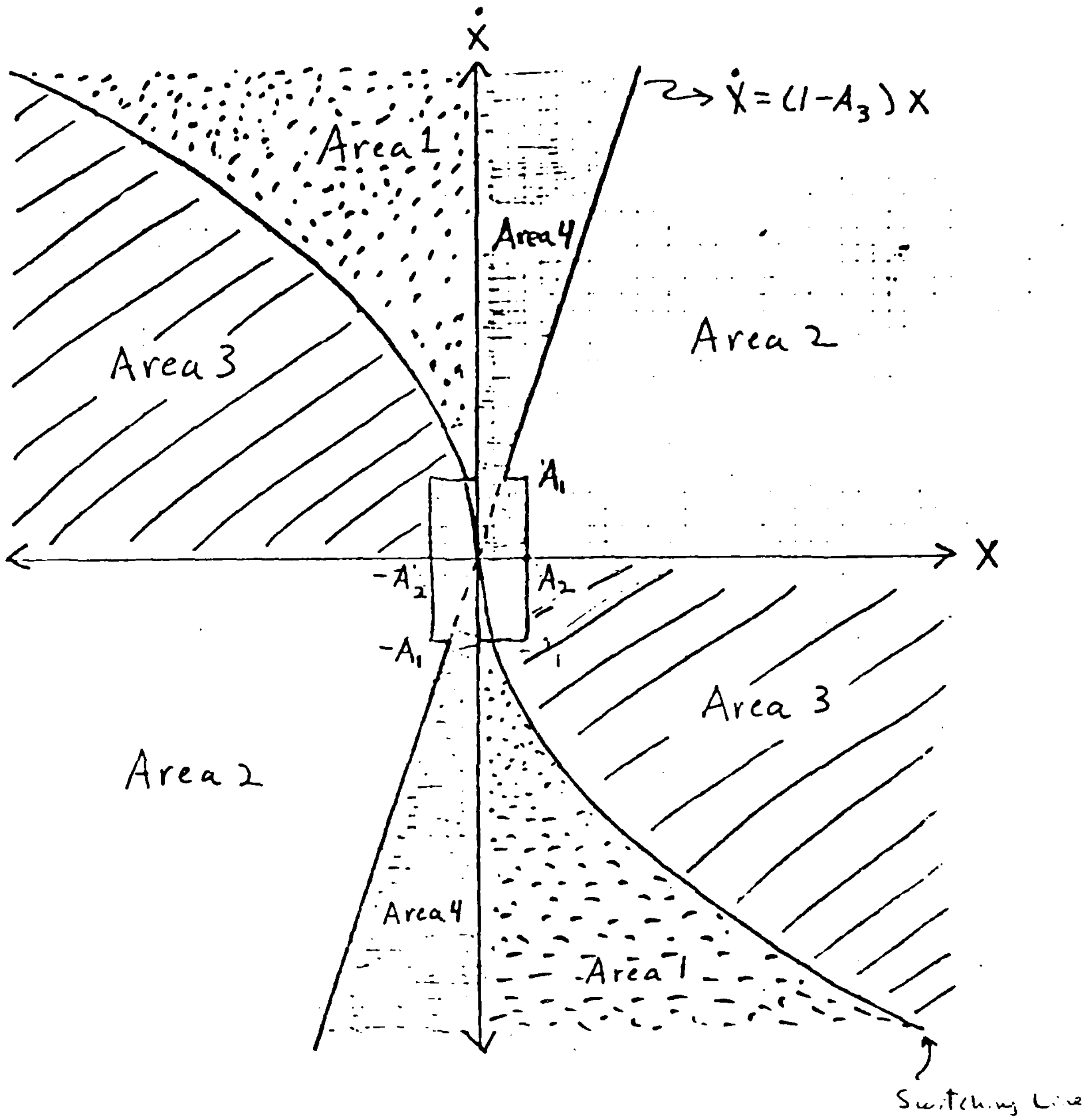

FIGURE 26: Categorization Algorithm for ERP Area Analysis

Figure 1.2.2.1

State-space plot of error position x velocity. Ideal switching line is shown. ERPs were averaged and compared when the error state was in the areas shown. Area 1: High demand. Area 4: Low demand.

conclusion on the basis of both studies is that the resources demanded by second order tracking, revealed in P300 attenuation, are relatively constant across the trial, a conclusion supporting the "central processing" hypothesis.

1.3 Integral "Object" Display and the Internal Model

(4.1.2, Gill, 1981). From our previous research we have repeatedly established that second order control is difficult and performed poorly. A major source of demand is the difficulty encountered in predicting the future state of the sluggish system, and exerting the corrective control at the appropriate time it is required before zero error is reached. This time is defined by the "optimal" switching curve (see 1.2.2 above). The present experiment contrasts conventional second order tracking with three "aided" tracking displays: Quickened tracking (Birmingham and Taylor, 1954), phase plane tracking, and a concept we have developed referred to as a pseudo-quickened display. In the quickened display a "quickened" error state is presented as a linear combination of error, error velocity and error acceleration presenting information designed to induce the optimal correction. In the phase plane display, a continuous two-dimensional representation of the values of error and error velocity is presented, along with an explicit line representing the optimum joint value of these two. In the pseudo-quickened display, only the true error is presented, but the cursor intensifies on one side, one reaction time before the switching line is predicted to be crossed, providing a cue as to when and in what direction to exert control (Figure 1.3.1).

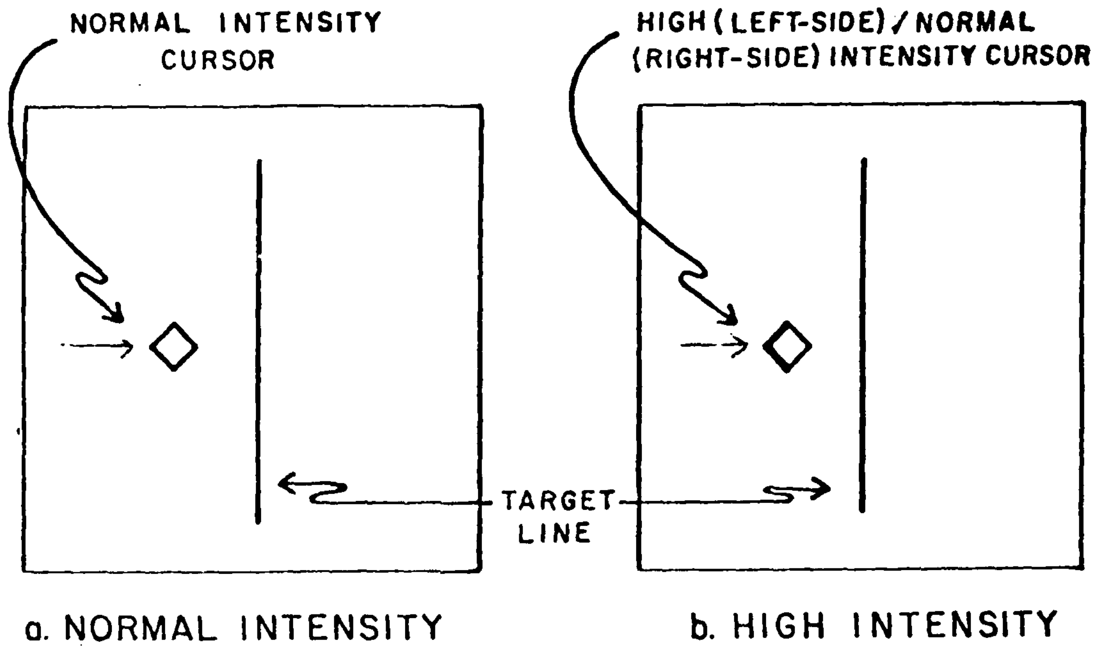

Figure 1.3.1

The Pseudo-Quickened Display.

(a) Indicates right movement is required.

(b) Indicates control should be moved to the left.

Differences in tracking performance among the various displays are expected and obtained, favoring the aiding schemes. The P300 workload index actually showed small effects favoring the quickened and pseudo-quickened displays over the unaided and phase plane displays. Of critical importance were the results of the transfer condition in which all three groups of subjects transferred to the conventional unaided display. After transfer the pseudo-quickened group showed significant and robust positive transfer relative to both the control and to the other two augmented training groups. This effect is revealed both in RMS error, and in the operator's "internal model" of the plant, as revealed by a state-space analysis (see below). The advantage to the pseudo-quickened display in training is apparently that is provides information concerning the optimal switching line in a manner that is integral to the error signal itself. Thus the "internal model" necessary for precise second order control may be acquired without excessive visual scanning in two dimensions (as is the case with the phase plane display). On the other hand, in contrast to the quickened display, the information of what the error is truly doing is accurately depicted with the pseudo-quickened display.

A related phase of this research concerned the representation and description of practice effects in second order control. It is clear that error is reduced as subjects practice. However, this information provides little insight as to how or why performance improves. Our hypothesis is that such improvement is based upon the development and refinement of a more accurate internal representation of the second order control dynamics. To infer the form of this internal model, we developed an algorithm for detecting control impulses, or discrete corrections in the operators responses. These responses were then identified as to their location within the state-space shown in Figure 1.3.1. Three measures of the fidelity of the internal model were adopted. (a) Where the switches fell relative to the ideal switching curve, as revealed by polynomial regression analysis. (b) Projections of where the control impulse would stabilize the system given that no disturbance was forthcoming. This projected value of the error at stabilization labelled X, proved to be a very revealing measure. In particular, the variance of X, but not its mean value, was highly correlated with overall tracking error on a trial-to-trial basis; served to discriminate "good" from "bad" displays; showed a pronounced development (smaller variance) with practice, and was the element underlying the positive transfer for the object display. These data suggest that the consistency of an operator's internal model is a critical element in control performance. Our technique, applied for the first time to continuous control, provides a useful way of operationalizing the internal model.

1.4 Auditory Tracking

(3.1.3) We have previously demonstrated that an auditory tracking display in which error is represented by a redundant pitch and localization cue provides adequate performance, although the level is not as high as when a conventional visual tracking display is employed (Isreal, 1980). This observation led us to conclude that the optimum use of the auditory display was not as a dedicated single channel source of error information, but as a redundant channel, available for use when the visual channel is overloaded with concurrent information processing demands.

To investigate this hypothesis, subjects performed a primary visual task requiring the perception of changes in acceleration of rotating targets. Concurrently they tracked an unstable element with either a visual, an auditory or a redundant visual-auditory display. In single task performance, auditory tracking was inferior to either the visual or to the redundant display. However when the primary task was introduced, the cost to performance of the visual task was greatest, and that of the redundant auditory display was the least, thereby establishing the advantage of redundant auditory-spatial information. Our current plans are to extend this research to a paradigm that requires concurrent processing of auditory verbal information.

1.5 Workload in Process Control Monitoring

This experiment extends our research to a class of tasks that are considerably greater in cognitive complexity than the manual control tasks employed above. Here we investigate the demands placed on an operator who monitors a complex, multi-element dynamic process, such as that involving the relation between flow, temperature, and pressure variables in a thermal or nuclear reaction process. Three questions are relevant in this task (1) What is the form of the operator's "internal model" of the process that is employed to assess whether the system is functioning normally or not? (2) How is the internal model related to individual differences in cognitive verbal or spatial ability? (3) How does the ERP reflect changes in plant status induced by legitimate and illegitimate (e.g., error) variable changes.

Our first experiment addresses the first two of these questions and evaluates the simulation that we have developed. A five variable plant is simulated and the variables are displayed in analog form. The subject monitors the system to detect and report abnormalities -- changes in the dynamic relation of the transfer function betwen elements -- that occur infrequently. This is the "primary task." To assess whether the cognitive processing that underlies this task is primarily spatial or verbal in nature, subjects perform a concurrent task, involving either spatial or verbal working memory. Differential interference effects are assumed to reflect differences in the format of the internal model.

The subjects are chosen from two distinct groups -- those assessed with high spatial and low verbal abilities, and those assessed with low spatial and high verbal abilities (see 3.3). This enables us to determine if the optimal mode of representation is more compatible with one or the other format. Data have currently been obtained on 14 of 18 subjects. We will examine in detail the nature of the two-way interaction in task interference measures between loading task (verbal-spatial) and ability (high verbal-high spatial). The results of this study will enable us to provide better insight into the nature of the process monitoring task, and based on this information, our subsequent investigations will examine ERPs elicited by the discrete, but subtle system failures.

2. ERPs and the Depth of Information Processing

The model that we have employed to account for a major source of variance in P300 amplitude, is one proposing that this variance relates to the amount of processing resources invested when updating an "internal model" of the environment on the basis of new stimulus information. This model has been used to describe sequential and probability effects in the oddball task, along with other aspects of the data. It is, as well, quite consistent with the workload effects described in the previous section, whereby fewer resources available for a more difficult primary task, allow less processing (and thereby smaller P300 amplitudes) to occur of the probes.

In the current section we extend some more general predictions of this model, by examining the extent to which any task or subject characteristics that force deeper, or more extensive processing of a stimulus will generate greater P300 amplitude. In Experiments 2.1 and 2.2, variance in "depth" is induced by varying the amount of information provided by a stimulus about a forthcoming event. In Experiment 2.1 the information concerns which of two "states" a hypothetical system is in. In Experiment 2.2, the information is a temporal warning about a forthcoming encounter with a vehicle in a driving simulation. Experiment 2.3 examines changes related to the depth of processing of learned material later reflected in memory, while Experiment 2.4 relates these "depths of processing" differences to differences in the salience of the encoded material. Finally Experiments 2.6 and 2.7 explore decreases in P300 amplitude elicited by task related stimuli as fewer processing resources are required following the development of automation and high levels of skill with the task of concern.

2.1 P300 and Information Extraction

(4.2.1, 4.2.2) One of the issues discussed in the previous section (Experiment 1.5) related to the utility of the P300 as an index of the amount of information extracted from variables in a complex process control monitoring task. The present experiment was designed to provide some basic data concerning the sensitivity of the P300 to reflect graded probabilistic information related to the status of a system. In the present experiment a hypothetical system is monitored and either one of two different system states can be in force (e.g., a normal or abnormal system). Information cues eminating from three different sources differ in their degrees of diagnosticity concerning the true state of the system. As this information is provided via the probabilistic cues, we periodically probe the subject for a response for an estimate of true system state. Response latency is used to infer the extent to which the subject has extracted the diagnostic information from the preceding stimuli (shorter latencies for expected probes associated with more diagnostic cues). We then examine P300 amplitude elicited by the diagnostic cue presentation, in order to determine how this covaries with the information content of (and information extracted from) the cues.

The data collected from 6 subjects indicate a considerable degree of individual differences. As assessed by response latency, some subjects extract a lot of information from the more diagnostic cues, some relatively less. For those subjects that do in fact extract progressively more information from more diagnostic cues, we observe a systematic change in N200 - P300 amplitude (greater for greater diagnosticity).

However, in all cases P300 was not large, and the particular experimental procedure was one that potentially introduced a CNV and readiness potential artifact. Therefore the experiment procedures are presently being altered in such a way that P300s will be larger, and a

CNV-indicing response will not be presented after each stimulus.

2.2 The Processing of Predictive Information

(Coles, Gratton, Clapman and Donchin, 1981) This experiment evaluated the ERP components elicited by a series of informative stimuli, presenting predictive information in a simulated driving task concerning a forthcoming event: The approach of an oncoming vehicle. The vehicle required an evasive maneuver. Since a major purpose of the experiment was to assess differences between the P300, CNV and Slow Wave component, the results will be discussed in detail in Section 5.1 (Other Components).

2.3 P300, Depth of Processing at Encoding and Memory

(2.2.3, Karis, Bashore, Fabiani and Donchin, in press) The purpose of this experiment is to examine in a verbal learning task whether differences in P300 elicited by words at the time they are learned will reflect their probability of being later recognized and recalled. The hypothesis is that P300 amplitude will index the degree or depth of processing, and this in turn will influence the strength of memory. The general approach is to present the words initially for encoding (training phase), then test them in a recognition test (test phase) and finally after several lists are presented in this format to have subjects attempt to recall all the words they can remember (free recall). ERPs to word presentation in both the training and test phases are recorded.

In our first memory experiment described in the original proposal 2.2.3, we found that words that were successfully free recalled had elicited larger P300s during the test phase than words not free recalled. We had intended to examine differences between the ERPs elicited by words in the original training phase as well, comparing ERPs to words that were later recognized correctly (in the test phase) versus those that were not. We were unable to do this in part because the words in the training phase often elicited very small P300s. The objective of the present experiment was to change the task so that large P300s were elicited in the training phase, so that we could make the comparison based upon recognition accuracy in the test phase, and not be required to rely entirely upon free recall. In the present "category experiment", by requiring a categorization during the training phase we force the subject to process each word more extensively, which should then result in larger P300s.

The design of this experiment was similar to the first, with a training phase in which half of the words (either dim or bright) are to be learned, followed by a subsequent test phase. The difference involved the word lists and the instructions to the subject. In the training phase half the words were dim, and half bright, as in the first experiment, but in the present experiment half of the bright and half of the dim words belonged to a single category (e.g., animals, female names). The subjects task, in this case, would be to remember the animal names that were dim (or bright, depending upon the condition) and ignore the other animal names. Then, in the test phase, the subject indicated, by pressing one of two buttons, whether the word just presented was, or was not, one of the category words she was trying to remember.

We have finished running eight subjects for this experiment, and are now analyzing the data. Preliminary results support our hypothesis and indicate that P300 amplitude is greater for words in the training phase that are recognized in the test phase than for words that are not recognized.

Since this experiment is more complex than the first, a detailed analysis of the various classes of words should be very interesting. There are category words that are to be remembered (category attend), category words that are to be ignored (category ignore), and non-category words. The non-category words are always to be ignored, but sometimes they are presented at the intensity of the category attend words, and sometimes at the intensity of the category ignore words. In addition, there are some words in the test phase that were not presented at all during the training phase. Finally we may examine P300 elicited during both the training and test phase, by words that either were or were not ultimately free recalled. A comparison of the behavioral and ERP data from these different classes should provide valuable information about the processes underlying the P300 and its functional significance.

2.4 The Von Restorff Effect: Encoding Salience

Our previous research on memory and P300 (Experiment 2.3, and Section 2.2.2 of original proposal) suggests that items that receive more processing at encoding will be better recalled, and will elicit larger P300s during encoding. In these experiments variance in processing "depth" is achieved via experimental instructions, or by random factors. The present experiment examines one well validated source of variance known as the Von Restorff effect. This refers to the benefit to later recall observed by items that are some how different or more "salient" than others. In our experiment, a relatively long series of homogeneous items is presented to a subject, who is required to memorize as many of them as he can. An item differing in some aspect (size: bigger or smaller) from the other items is inserted in the middle of the list. These isolated items are remembered better than are homogeneous items in the same position, demonstrating the Von Restorff effect.

The basic hypotheses are that we expect to find a larger amplitude P300 for items that are later recalled (whether isolated or not). We expect also to find a bigger P300 for the isolated items in general. The results for the first subjects seem to confirm the hypotheses. The Von Restorff words are better recalled, and generate larger P300s at the time of encoding. Further analyses of the data of all subjects is proceeding (Figure 2.4.1).

2.5 Automatic and Control Processing

(4.4.1.1) The research of Schneider and Shiffrin (1977) has demonstrated that when a set of target letters in a large array are consistently responded to as targets, they will eventually be processed in a qualitatively different manner from target letters that are not consistently assigned. This processing mode is termed automatic processing. It is assumed to be fast, parallel and effortless, and is in marked contrast to the processing of letters that are sometimes targets and sometimes not. These receive control processing; which is slow, serial and resource demanding.

The purpose of the current study was to evaluate the relationship between reaction time and the P300 component of the event-related brain potential in tasks in which either a controlled or automatic process was operating. At issue is whether the development of automatic processing generates P300s of progressively lower amplitudes, as the amount of resources required to identify a stimulus as a target diminishes. The paradigm employed to investigate this relationship was similar to the task used by Schneider and Shiffrin (1977). In the consistent mapping (CM) condition designed to induce automatic processing, targets were always selected from one category (numbers 1 to 9) while distractors were chosen from another (letters A to I). In the variable mapping (VM) condition which produces control processing, both targets and distractors were chosen from the same category (letters A to I). Targets and distractors exchanged roles over trials in the VM condition. Each trial began with a 10 sec presentation of the memory set (either 1 or 4 items). In the 30 frames which followed the presentation of each memory set, the subjects task was to indicate whether a memory set item (positive set) was present. Subjects did not respond on trials in which only distractors (negative set) were displayed.

Subjects participated in 14 sessions, totaling approximately 13,420 trials over the course of the study. Reaction time was recorded in all of the sessions while EEG was collected in the first and last session. Thus the development of the automatic processing response was also examined.

Reaction time results were consistent with previously obtained findings (Schneider and Shiffrin, 1977). There was a significant interaction between training condition (automatic vs. control) and memory set size (one vs. four). Reaction time in the VM condition was longer at the larger memory set size, while there was no difference as a function of set size in the CM condition suggesting development of automatic processing only in the latter condition. P300 latency yielded results similar to reaction time. Again there was a significant training condition by set size effect. Furthermore, P300 latency was longer for the negative that the positive trials. Because of the relatively high degree of latency variability in the P300 of the VM conditions, compared to the CM conditions, the wave forms must be latency adjusted via Woody filtering before P300 amplitudes may be compared. This analysis is now in progress.

2.6 P300 Processing Resources and Practice

(Wickens, Kramer and Donchin, 1981) The results of some aspects of this experiment have been reported previously (2.1.1). Subjects performed a simulated target acquisition task in which a moving target was to be "captured" by manipulating a control stick to drive a cursor on top of the target. Once spatial error was reduced the subject was required to track the angular velocity of the rotating target until this was matched. Capture could then be completed. In different experimental conditions control was exercised via either a first order or mixed first and second order plant. This manipulation of control dynamics replicated the effects of increased workload and power performance reported in 1.1 and 1.2. In four different versions of the experiment subjects also counted probe stimuli in either the visual (Experiment 2 and 4) or auditory (Experiment 1 and 3) modality.

From the point of view of the present analysis, the critical difference between the four experiments related to the amount of practice subjects received prior to each experiment. This increased monotonically from 30 acquisition trials in Experiment 1, to 570 trials in Experiment 4. Our interest was in the changing effect of the control order manipulation in P300 amplitude as a function of extensive practice or "automation" of the acquisition task.

The results shown schematically in Figure 2.6.1 support the hypothesis that increasing practice (a) reduces the resource demands of the primary task, and (b) reduces the differential resource demands between first and second order tracking. Thus in Experiment 1, both versions of the acquisition tasks consumed full resources, leaving none available for the probe task. P300 was absent. In Experiments 2 and 3, P300 was less attenuated in first than second order tracking, but visible with both. In Experiment 4, both versions were now performed at a relatively "automated" level. P300 was large for both, failed to reveal difference in resource demand. Thus the P300 workload index revealed the joint effects of practice and workload demands of the complex task.

2.7 Automated Performance in a Complex Task

(4.4.1.2) In this experiment we are concerned with the development and manifestation of high levels of skill in a task of far greater complexity than the letter identification task in Experiment 2.5. Our interest is in the training process, the decomposition of the task into its elements, and the extent to which the high skill levels are reflected in primary task (intrinsic) and secondary task ERPs. The task we use, Space Fortress (SF), is a complex simulated space task in which the subject is required to manipulate a space ship, shoot lasers at space mines or a space fortress, and avoid getting destroyed by a mine or by a fortress missile. We measure various aspects of the subject's performance including efficiency of laser firing, ability to survive, speed of destroying enemy mines, or fortress hit rate. During training, the subject begins with a fairly easy version of one of the tasks (mine alone or fortress alone). Then, every

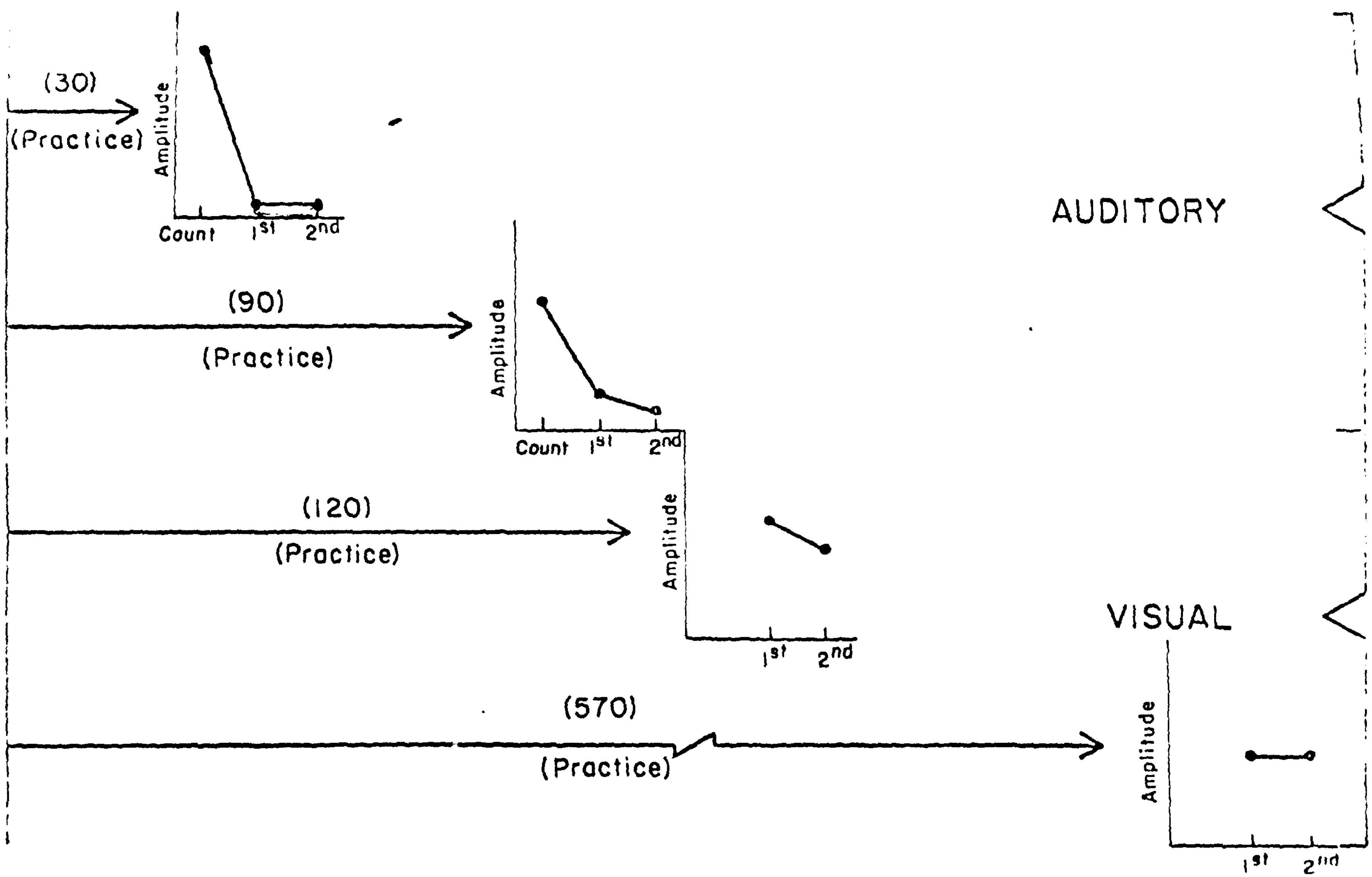

Figure 2.6.1

Schematic representation of effects of task difficulty (control order) and practice on ERPs in target acquisition task.

time his performance exceeds criterion (defined in terms of ability to survive and destroy mines or the fortress) we change a parameter of the task to make it more difficult. In the mine task, for example, we may increase the speed of the mines, or make mines difficult to identify by varying the memory set which defines mines which can be destroyed by the subjects lasers. In the fortress task, we may vary the effective range of the subject's lasers or the speed with which the fortress shoots at the subject's ship. Training proceeds until the subject has mastered the task with the parameters set at the highest level of difficulty. Then, the subject is trained on the other task, and finally, performs both tasks simultaneously. Acquisition curves for each task are plotted for different performance measures and scrutinized to determine the degreee to which skill on one task transfers to the other. For each task separately, we also perform an additive factors procedure. Task variables relating to perceptual-motor load, memory load, and perceptual load alone are manipulated such that performance measures are obtained for every level of every variable when crossed with every level of every other variable. Scrutiny of the performance measures reveals which components of the task are "isolable". We propose that this procedure will aid in the construction of sub-tasks on which practice can be given to benefit performance on the whole task. We also propose that the identification of isolable components will aid in the analysis of the effects of stress on performance. Measurement of ERPs will soon be added to the task to test hypotheses relating the magnitude of ERP components to the reduced processing requirements, associated with high levels of skill proficiency.

3. Individual Differences

A series of four experiments have been designed to evaluate the possibility that individual differences in cognitive performance may be correlated with individual differences in some attributes of the ERP. In Experiment 3.1, two differences in cognitive performance are evaluated in performance of a same-different word judgment task: (1) subjects of high and low verbal ability are contrasted, (2) the data reveal a contrast between two qualitatively different styles of processing, differentiated both by reaction time and by the ERP. Experiment 3.2 examines the relationship between the verbal-spatial abilities dimension of individual differences, and an information processing dichotomy related to the comparison described above and defined by a holistic-analytic dimension. Experiment 3.3, has been described in Section 1 (Experiment 1.5), contrasting subjects of high verbal and high spatial ability in a process control monitoring task. Finally, Experiment 3.4 examines individual differences in absolute pitch as a means of testing a hypothesis about the relation of P300 to short-term memory.

3.1 Mental Chronometry, Orthography and Phonology

(3.4.1, Kramer, Ross and Donchin, 1981). In this experiment, two hypotheses were tested:

1. N200 and P300, components of the ERP offer additional insights into the processes involved in a simple word processing task. Specifically, the N200 will provide an indication of subject's "mismatch detection" while P300 will prove to be a sensitive metric of subject's categorical decisions.

2. Individual differences in performance are reflected in the chronometric analysis of the task, and ERPs can aid in the localization of these differences to specific stages of processing.

Forty right-handed subjects (20 male) participated in the study. They were selected from a population of 400 undergraduate students on the basis of their scores on the Nelson Denny Reading test (20 good and 20 poor readers .

The subjects performed a word comparison task in which they were required, in different conditions, to decide whether two visually presented words either looked alike (orthographic match condition) or rhymed (phonological match condition) (Polich, McCarthy, Wang and Donchin, submitted). The two words were considered to be orthographically similar if all but their first letter matched. Subjects depressed one response button if the words were the same and another if they were different.

Each subject received all of the 200 word pairs in each condition (50 per list). Subjects were unable to predict which items would be presented on any trial since word pairs occurred randomly and with equal probability. The lists were composed of words which:

a) Rhymed and looked alike (RO, Match - Patch): "Yes" in both conditions

b) Rhymed but did not look alike (R, Blare - Stair): "Yes" - Rhyme, No - Orthography

c) Looked alike but did not rhyme (Wo, Catch - Watch): "No" - Rhyme, Yes - Orthography

d) Neither looked alike or rhymed (W, Shirt - Witch): "No" in both conditions

Analysis of the mean reaction times revealed the following significant effects:

1. Visual-orthographic reaction times are faster than rhyme reaction times (679-828 msec).
2. There is a significant interaction between condition and list. In each condition slowest responses were produced when a negative mismatch response was required to the relevant attribute (rhyme or orthography), but the irrelevant attribute matched. That is,
   a. In the visual condition, the R list (orthographic mismatch, phonological match) yields the slowest reaction time.
   b. In the rhyme condition, the Wo list (orthographic match, phonological mismatch) produces the slowest reaction time.

With regard to individual differences in reading ability the most pronounced and consistent effect was that poor readers err more than good readers. In addition, poor male readers were slower to respond in the rhyme condition than the other three groups.

A second noticable difference in reaction time was observed that transcends the two reading ability groups. Visual inspection of the data indicated that two groups of subjects could be differentiated on the basis of their reaction time performance in the visual condition. One group of subjects (Type 1: 9 subjects) showed no significant difference in response latency across the four lists (Figure 3.1.1). The second group of subjects (Type 2: 31 subjects) portrayed the typical pattern of reaction time results found in the grand averages (Figure 3.1.2). There was no significant difference in rhyme reaction time or errors between the two groups.

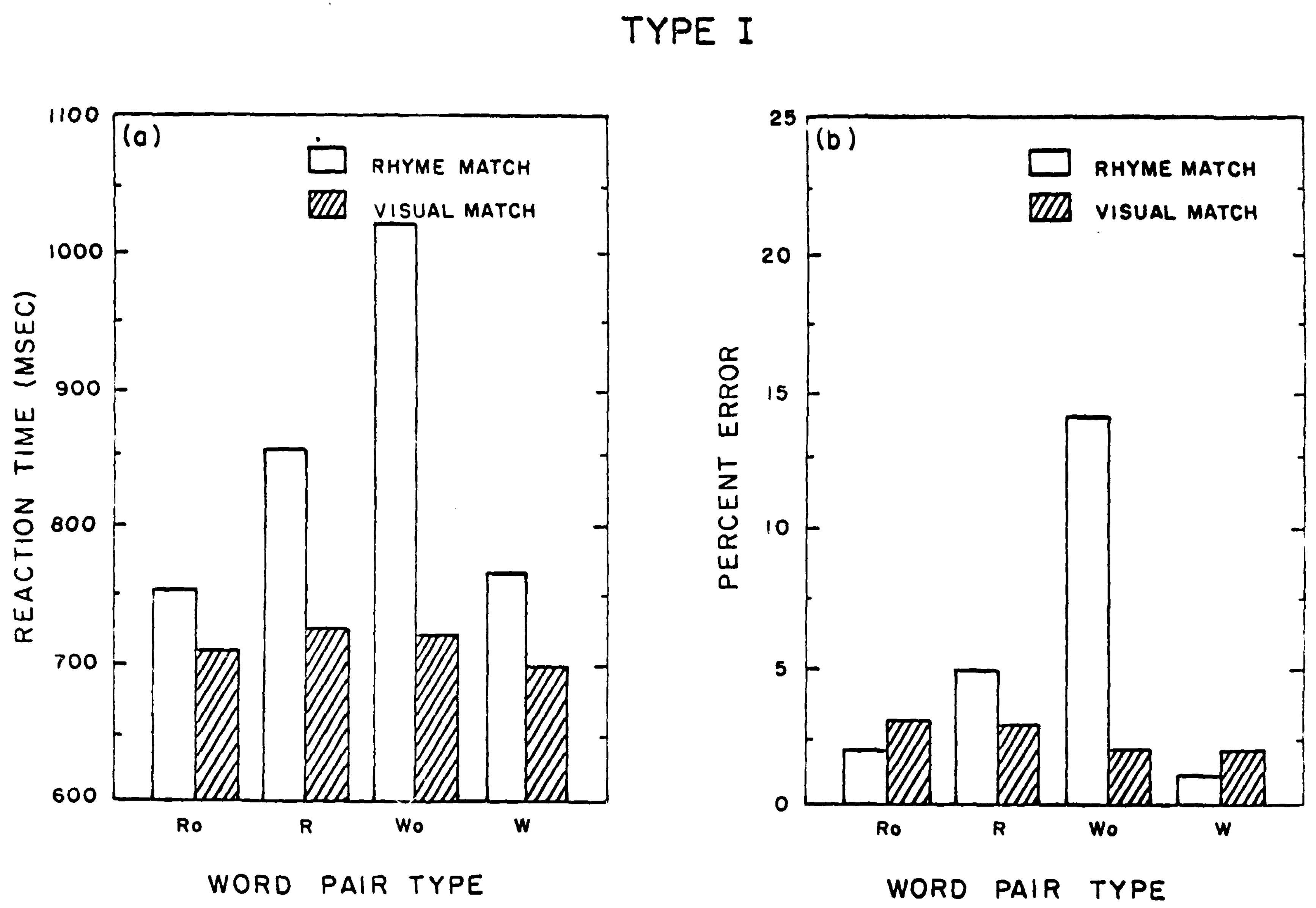
TYPE I
(a)
RHYME MATCH
VISUAL MATCH
REACTION TIME (MSEC)
1100
1000
900
800
700
600
Ro
R
Wo
W
WORD PAIR TYPE
(b)
RHYME MATCH
VISUAL MATCH
PERCENT ERROR
25
20
15
10
5
0
Ro
R
Wo
W
WORD PAIR TYPE

Figure 3.1.1

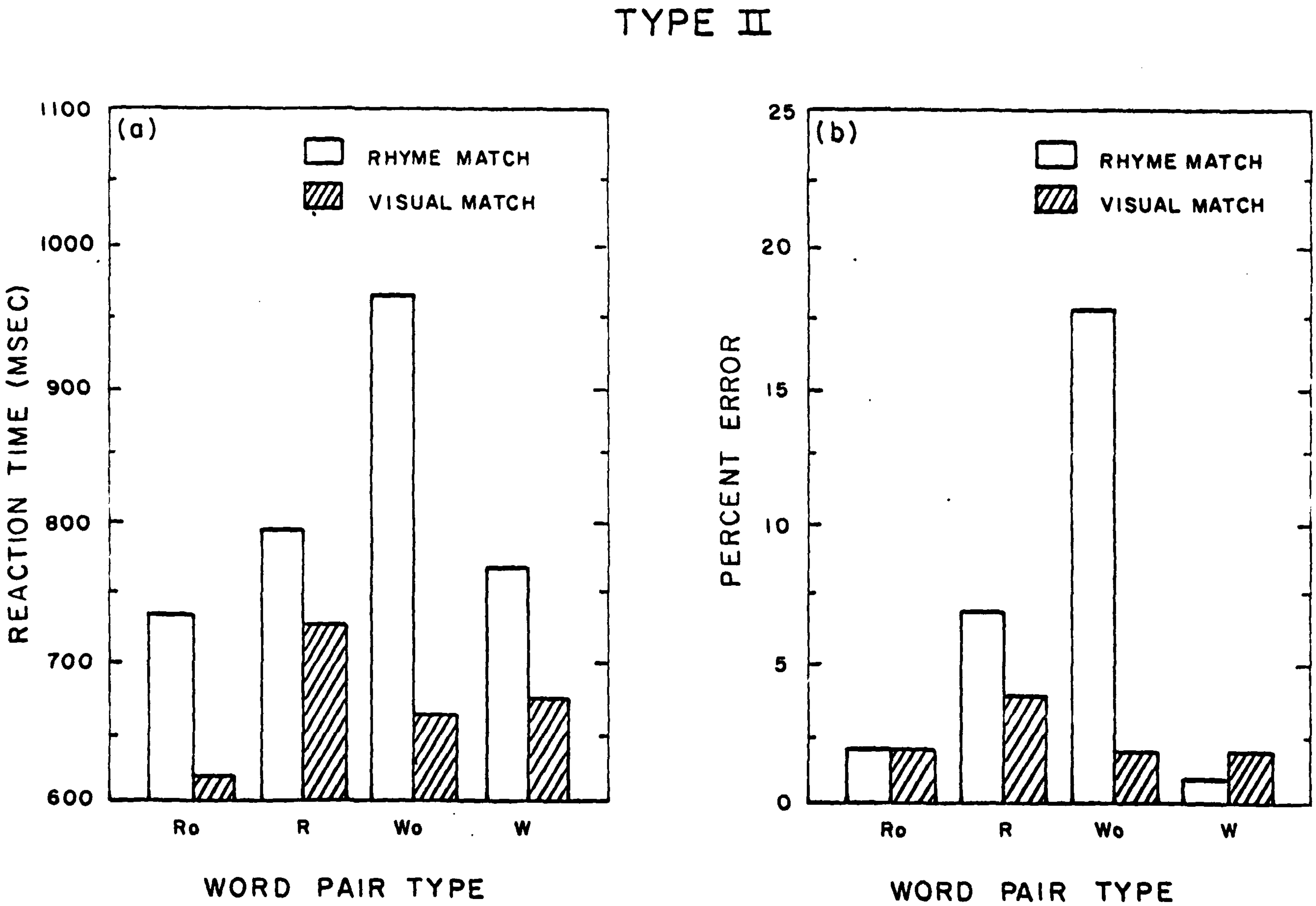
TYPE II
(a)
RHYME MATCH
VISUAL MATCH
REACTION TIME (MSEC)
1100
1000
900
800
700
600
Ro
R
Wo
W
WORD PAIR TYPE
(b)
RHYME MATCH
VISUAL MATCH
PERCENT ERROR
25
20
15
10
5
0
Ro
R
Wo
W
WORD PAIR TYPE

Figure 3.1.2

In interpreting this difference, Type 1, in contrast to Type 2, processing is characterized by visual processing that is equivalent for visual matches and mismatches, and is unaffected by phonological features (that is, neither helped by matches along the irrelevant phonological dimension, nor hindered by phonological mismatches).

The assessment of how both dimensions of individual differences (high vs. low verbal, and Type 1 vs. Type 2 processors) were reflected in the ERP waveforms revealed the following effects:

A. Equivalent Across All Groups

1. In both rhyme and orthography conditions, N200 amplitude is largest when the orthography of S2 is different than S1 (W, R). (Figure 3.1.3)
2. In the rhyme condition, a phonology mismatch (Wo and W) produces a long latency N200 and P300.
3. In the visual condition, an orthography mismatch (R) increases the latency of the P300.

B. Individual Differences

1. The differences between good and poor readers were not pronounced. However, P300 amplitudes were in general larger for good readers in both conditions in all trials in which either orthography of phonology produced a mismatch (i.e., R, Wo and W).
2. The differences between Type 1 and Type 2 subjects are more pronounced, and are characterized by these main effects (Figure 3.1.4 and 3.1.5):

   a. Type 1 subjects have shorter latency P300s than Type 2

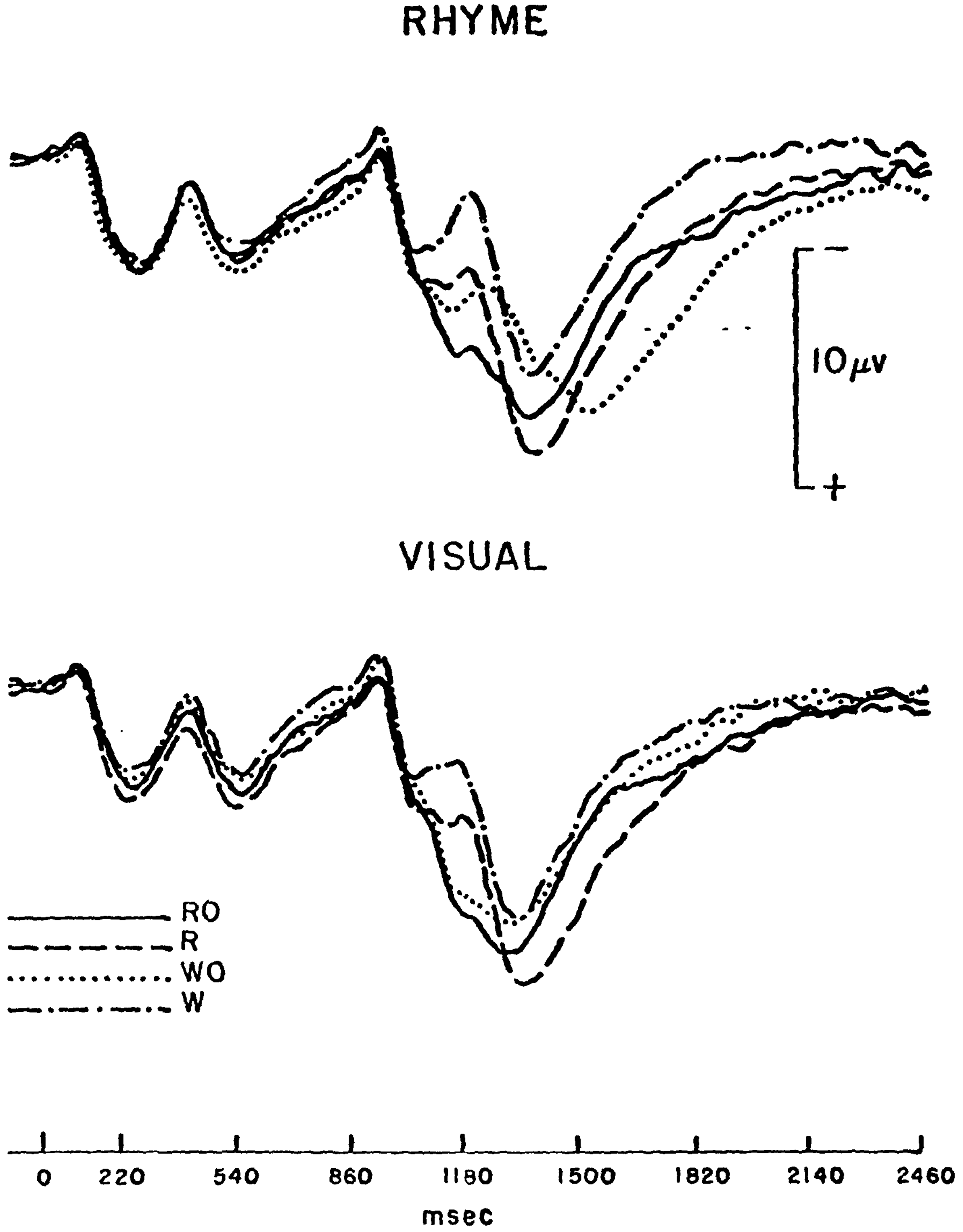
RHYME
10μv
+
VISUAL
RO
R
WO
W
0
220
540
860
1180
1500
1820
2140
2460
msec

Figure 3.1.3

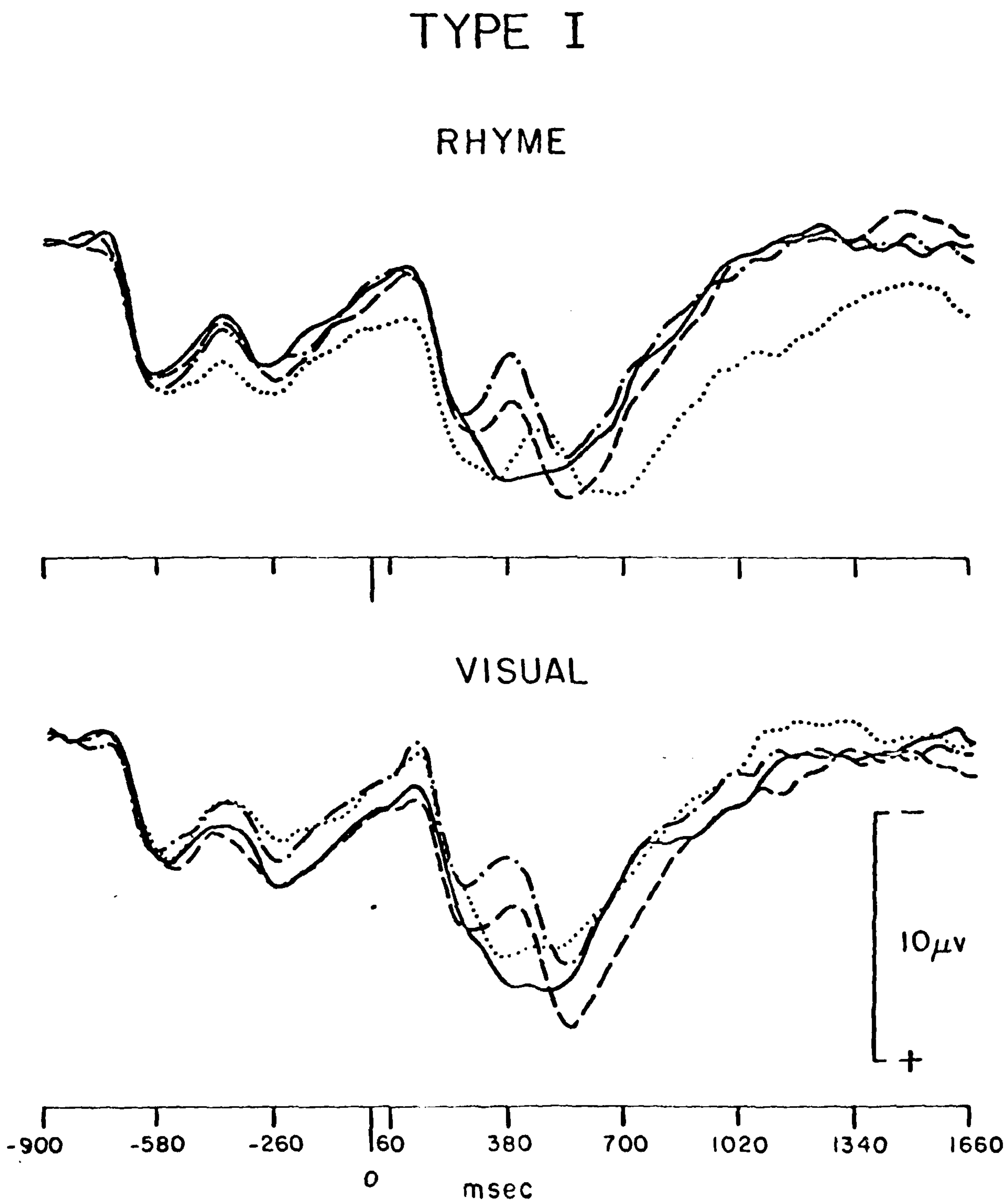
TYPE I
RHYME
VISUAL
10μv
-
+
-900
-580
-260
60
380
700
1020
1340
1660
0
msec

Figure 3.1.4

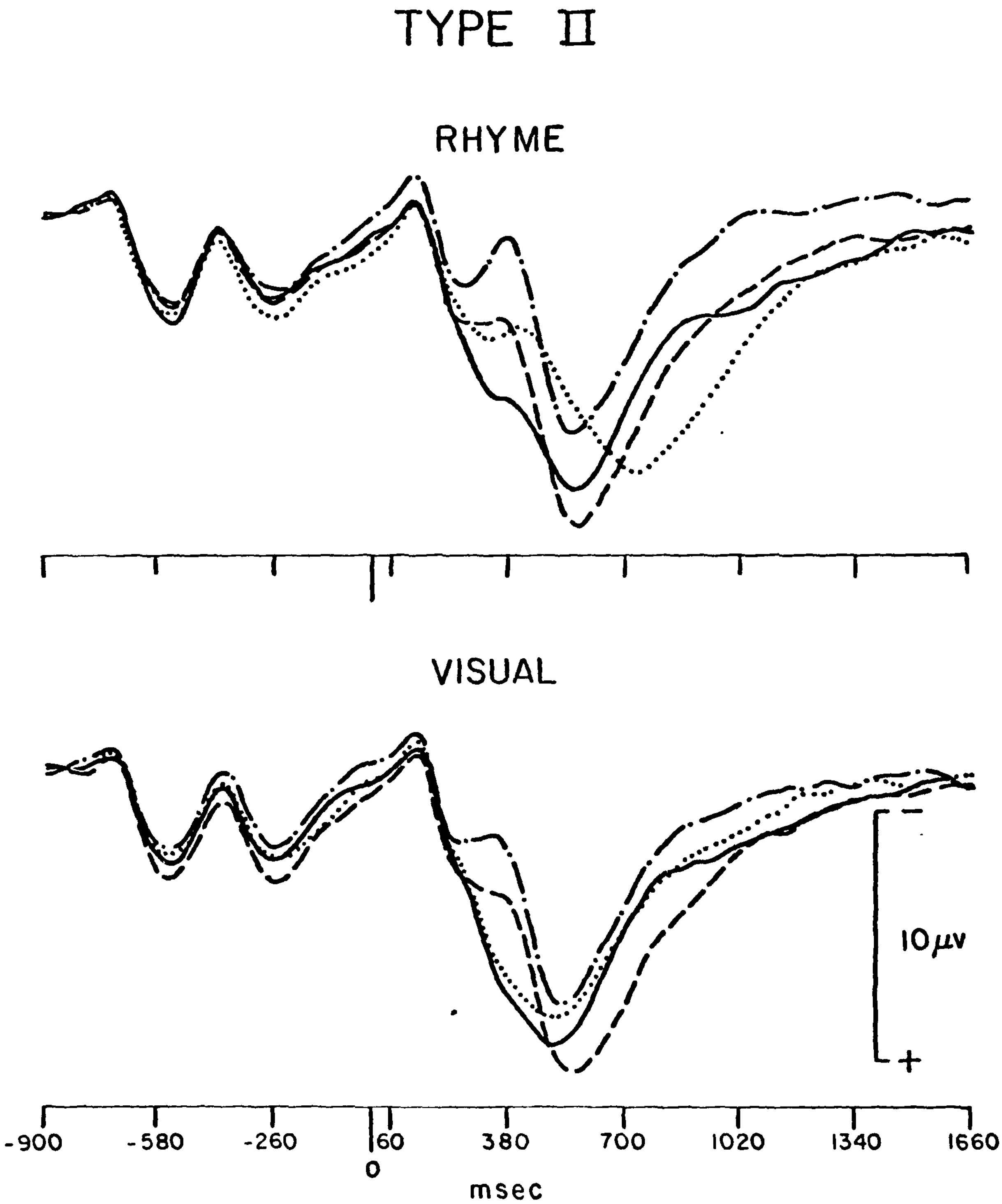
TYPE II
RHYME
VISUAL
10μv
-
+
-900
-580
-260
0
60
380
700
1020
1340
1660
msec

Figure 3.1.5

subjects in all four word pair lists and both experimental conditions.

b. P300 amplitude is larger for the Type 2 than Type 1 subjects.

c. N200 peak-peak amplitude is different between the two groups. P200-N200 amplitude is larger for the Type 1 than Type 2 subjects, while N2000-P300 amplitude is larger for the Type 2 than Type 1 subjects.

We are currently attempting to interpret these results within the framework of a model of orthographic and phonological processes in encoding.

3.2 ERP Differences in Analytic and Holistic Processing

(4.4.2.2) As in Experiment 3.1, Cooper (1975) has also dichotomized subjects on a "Type 1 - Type 2" dimension in terms of the pattern of their reaction times in a paradigm requiring judgment of the identity of two sequential geometric figures. Type 1 processors make such comparisons in a holistic "template matching" fashion, while Type 2 processors proceed via a more analytic feature-by-feature comparison. A test has been developed in our laboratory that appears to be able to discriminate analytic from holistic processors following a very brief and simple procedure.

This test has been administered to some 200 undergraduates and we are currently assessing if the dimension predicts performance in Cooper's paradigm. Our intentions are to assess how this dimension correlates with individual differences in verbal ability and general intelligence (preliminary data suggest that the latter correlation is low). Then we shall collect ERP data from both groups of subjects in Cooper's paradigm to determine the manner in which the analytic-holistic dimension is reflected in the components of the waveform. This will assist us in determining the processing locus of the dimension.

3.3 Individual Differences in Process-Control Monitoring

(4.4.2.1) This experiment was reported under Section 1.5, and is designed to assess the manner in which subjects of low and high verbal and spatial abilities perform in a complex process-control monitoring task. The intent is to use this dimension, in conjunction with verbal and spatial loading tasks, to infer the nature of the "internal model" employed when carrying out such tasks.

3.4 Absolute Judgment of Pitch and Short-Term Memory

The purpose of this experiment is to compare the processing of tonal sequences of two groups of subjects (consisting of individuals with perfect pitch (PP) and those without (NPP). The notion is that individuals with perfect pitch (PP) do not have to make comparisons between incoming tonal stimuli and representations held in short-term memory, a comparison which is assumed to generate a major component of P300 amplitude in the oddball count task. Rather, they maintain a permanently established comparison standard for tones. If this is so, then our current notions regarding P300 would predict PP subjects will not show the standard oddball effects, at any ISI, for auditory stimuli. They should either produce an equal P300 for the frequent and rares, or produce no P300 for any tone. We would thus also expect differences between PP and NPP subjects in the discriminant scores in sequential probability trees, differences that could perhaps be quantified in terms of different short-term memory decay rates in the expectancy model described in Squires, Petuchowski, Wickens and Donchin (1977). We would not however expect these differences between groups to be manifest in visual oddball experiments. We have presently identified a relatively substantial group of PP subjects who are willing to serve. Data collection is beginning at this time.

4. P300, Response and Processing Latency

Our investigations of the relation between P300 latency, and RT latency, following from the initial study by Kutas, McCarthy and Donchin (1977) have revealed considerable insights into the chronometric analysis of processing. Four experiments described below continue to explore this relation. Experiment 4.1 explores in detail the nature of the "delayed P300s" that occur in a reaction time task when errors are made. Experiment 4.2 investigates in greater detail the nature of the prolonging effect of noise in stimulus evaluation. In Experiment 4.3 we extend our investigation into the nature of the delay in processing produced by conflicting responses, by employing EMG analysis in conjunction with ERPs and overt responses to provide us with greater analytic power. Experiment 4.4 employs a similar combination of RT, EMG and ERP variables to estimate the time required to transfer information between the two cerebral hemispheres.

4.1 Errors, P300 and the Speed Accuracy Tradeoff

(4.3.2) Investigators of mental chronometry have proposed P300 latency as an index of stimulus evaluation time that is independent of response selection and execution (Donchin, 1975; Kutas et al., 1977; McCarthy and Donchin, 1981). While the focus of most of these studies has been on the relationship between P300 latency and reaction time (RT) during trials on which a correct response has been made, a few investigations have examined this relationship on individual error trials. Kutas et al. (1977) reported that for error trials (presentation of a rare stimulus to which the subject responded "frequent") P300 latency typically exceeded RT as if the subject continued to process the information provided by the stimulus even though a response had been made. Similar results were reported by McCarthy and Donchin (1979) in a study in which many more error trials were obtained and more subjects were employed. Three alternative interpretations may be provided to the finding that P300 latency is later than RT on error trials:

1. P300 follows evaluation, not of the experimental stimulus, but of the rare event of making an error. This interpretation implies that errors are detected, that errors are rare and are relevant.
2. P300 to the experimental stimulus is delayed by detection of an error in stimulus evaluation on fast guess trials.
3. P300 to the experimental stimulus is delayed by detection of an error in response selection and execution on fast response trials.

A study is currently being designed to investigate these interpretations. Subjects will be asked to perform a choice reaction time response to various male vs. female names. In different conditions, subjects will be asked to maximize the speed or accuracy of their response. In addition, two levels of probability of stimulus category will be used: 20/80 and 50/50. This study will permit detailed assessment of changes in cognition and behavioral functioning with changes in information processing strategies.

4.2 P300 Latency Prolonged by Noise

We, and others, argued that P300 is related to a stimulus evaluation process, but not to response initiation decisions. McCarthy's recent dissertation manipulated variables designed to affect the stimulus evaluation stage and the response decision stage. To manipulate stimulus evaluation time, McCarthy varied the nature of the noise characters (##### vs. random letters) surrounding the words "left" or "right". To manipulate the response decision time, a compatible or incompatible response was required (i.e., a left hand response to "left" would be compatible while a right hand response to "left" would be incompatible.)

If the manipulations of noise characters and SR compatibility are affecting different stages, they should not interact according to the additive factors model. Examining RT, McCarthy found that the type of noise characters and SR compatibility produced the expected findings of significant main effects but no interaction. Examining the P300 latency, it was clear that response compatibility had no effect. These data provided further support to the hypothesis that P300 latency is related only to stimulus evaluation processes.

The relationship between P300 latency and the type of noise characters was unclear, however. The ##### noise condition gave a single late positive component peaking at about 400 msec at the Pz electrode. The random letter noise condition produced 2 LPCs, the first peaking (at Pz) about 400 msec post-stimulus and the second at about 650 msec. McCarthy and Donchin (1981) argued that the second LPC was in fact, the P300. Therefore, the P300 latency was affected by the type of noise characters present.

The present experiment is designed to examine further the relationship between the type of noise characters and the latency of the late positive component(s). This will be done by presenting four noise conditions, rather than only two as McCarthy has done. In each condition, the word "right" or "left" will be surrounded by the noise characters. Subjects again will be required to make a compatible or incompatible response. The flanking noise will consist of (1) a series of #####, (2) numbers, (3) backward letters, and (4) forward letters.

As in the McCarthy thesis, each of these conditions will be combined with the SR compatibility factor. Presumably, RT will be affected by both the type of noise and by SR compatibility, but no interaction will be observed.

Of critical interest here will be the effect of noise type on the latency of the late positive components(s). If the second LPC observed in the McCarthy thesis is in fact a P300 type phenomenon, then its latency should be affected by the type of noise characters used. Furthermore, the noise variable should affect RT and the second LPC in a similar manner.

4.3 The Locus of the "Response Conflict" Effect

(4.3.2.2) This study is a replication and extension of an experiment by O'Hara, Morris, Coles, Eriksen and Morris (1981) who evaluated the effects of compatible and incompatible noise on RT and EMG activity. Subjects were required to respond to target letters (S or H) with right or left hand button presses. On some trials the target letter was surrounded by compatible noise letters (e.g., SSSSS or HHHHH), while on others noise letters were incompatible with the target (SSHSS or HHSHH). In each case the middle letter is the target letter. Eriksen and his colleagues have shown that RT to the targets surrounded by incompatible noise is consistently larger than when flanked by compatible arrays. In the O'Hara study we found that on about 60% of the incompatible noise trials EMG activity in the incorrect arm occurred and preceded EMG activity in the correct arm. For compatible trials, only 5% of the trials were associated with EMG activity in both arms. (For all these trials, the correct response was made, even though EMG activity in the incorrect arm occurred). Interestingly, trials where EMG activity only occurred in the correct arm, were considered separately. The difference in RT between compatible and incompatible noise was substantially reduced. These results suggested that the overall difference in RT between compatible and incompatible trials is due mostly to response competition.

In the present experiment we attempted to replicate and extend these findings by (a) including ERP measures, (b) presenting compatible and incompatible noise stimuli in left, right, or both visual fields, and (c) using squeeze rather than button press responses.

ERPs were included because (a) if P300 is a measure of stimulus evaluation time independent of response competition, then P300 latency should be the same for compatible and incompatible trials, (b) noise stimuli were presented to different hemifields and this may be associated with lateralized ERPs, (c) we were interested in tracing the processes between stimulus presentation and response beginning with stimulus evaluation (ERPs) and ending with response execution (EMG and dynamometer squeeze). A squeeze response was used to provide a finer gradation of the subject's response than is available with a simple button press.

We should also note that a related question concerned processes associated with error correction. In the previous experiment, too few error trials were obtained to permit an analysis of errors. Thus, in the present experiment each subject performed 2160 trials.

At the present time the data from four subjects, each participating in roughly 12 hours of data collection, have been acquired. These are presently undergoing analysis.

4.4 Interhemispheric Transmission Time

The time required to convey information between the two cerebral hemispheres over the commissural pathways connecting them is referred to as interhemispheric transmission time (IHTT). This transmission rate is typically estimated in humans by measuring reaction time (RT) to the presentation of laterally positioned unpatterned stimuli. A recent review of this literature concluded that RT estimates of IHTT are too variable to provide a valid measure of IHTT (Swanson, Ledlow, and Kinsbourne, 1978). In this review, however, the authors failed to differentiate RT procedures on the basis of task demands. Consequently, Bashore (1981) recently challenged their conclusions and demonstrated that reliable estimates of IHTT can be obtained using simple RT procedures. The appropriate parametric analyses have not been performed, however, using more complex RT tasks to permit a judgment to be made about the validity of these procedures. Further, we have suggested that the combined use of RT, EMG, and ERP measures will allow us to dissect the commissural transfer process with greater precision.

Accordingly, we initiated a series of experiments designed to estimate IHTT in tasks of carefully graded complexity. The first studies compare estimates derived from RT and combined EMG/RT measures. Data have been collected from 49 subjects in a GO-NO GO task in which RT was the only dependent measure. A black dot was presented tachistoscopically to the left or right of visual fixation, to which the subject responded with a button press with his/her index finger. On one-third of the trials, no dot appeared in the lateral half-field and, on these trials, the subject was required to withhold his response.

We failed to find an interaction between differential hemispheric activation and motor control output and, as a result, we were unable to derive an estimate of IHTT. Thus, our analyses indicate that RT cannot be used alone to measure IHTT in a GO-NO GO task using a black dot as the target stimulus. In a second experiment, we measured EMG/RT in six subjects while they performed simple and GO-NO GO RT tasks. Again, the target stimulus was a black dot. Our preliminary analyses indicate, in agreement with the first experiment, that RT alone is not sufficiently sensitive to provide a reliable estimate of IHTT when the target stimulus is a laterally placed dot. However, we have partitioned trials on the basis of EMG activity (false starts in the incorrect hand vs. no false starts) and our preliminary analyses suggest that the EMG may provide a means by which IHTT can be more finely measured. On trials in which there are no false starts, there is evidence of an interaction between stimulus input/motor output which permits an estimate of IHTT to be derived.

These data have encouraged us to initiate a series of experiments in which we vary stimulus intensity and duration, and assess their effect on estimates of IHTT using RT, EMG, and ERP as independent variables.

5. Other ERP Components

In most of the research described above our interest has focused on the P300 component of the waveform, although other ERP components have been considered to the extent that they provide informative results. The present series of three experiments differs from the preceding one in that experimental interest is focused explicitly on other components. In Experiment 5.1 our interest is in the CNV and Slow Wave components and their association or dissociation with P300 in a complex task. Experiment 5.2 examines the laterality of the readiness potential associated with left and right handed movements of left and right handed subjects. This procedure provides a means of validating a model of laterality of motor control and understanding the nature of voluntary movements. Finally, Experiment 5.3 continues our research into the "Semantic Incongruity Effect", as reflected in a negative component (N200 or N400), by examining the response of this component to words of varying degrees of proximity to each other in "semantic space".

5.1 P300, CNV and Slow Wave Components

(Coles, Gratton, Clapman and Donchin, 1981). This experiment was designed to evaluate the relationship between ERP components (especially CNV and Slow Wave) and behavior in a complex task. Subjects performed a simulated driving task (presented on a CRT display) in which they controlled the speed and location of a "car" with a joystick as it travelled along a road. From time to time, obstacles appeared on the road and the subject had to avoid them by manipulating his car. The subject's car was equipped with a radar device which gave him advance warning information concerning the forthcoming appearance of obstacles. This information was provided in the form of a number which appeared inside the subject's car and which proceeded to count down to zero at intervals of 2.25 sec. At zero, the obstacles appeared. Different trials were associated with count downs consisting of either 5, 3, or 1 number(s).

The first numbers (5, 3, or 1) were associated with a large Slow Wave ERP component; the number 1 (regardless of the starting number) was associated with a large CNV component. Furthermore, both components were larger when the subject slowed down soon after appearance of the final warning number 1, than when he slowed down later.

These data reveal that the two ERP components (CNV and Slow Wave) are dissociable in terms of the conditions which elicit them. The Slow Wave appears to be related to "context updating", while the CNV is related more to expectancy for action (Figure 5.1.1). In addition, these components are related to the subjects' behavior. The experiment also revealed that reliable ERP measures can be obtained in a complex tas) ind provided an opportunity for us to evaluate the eye-movement correction procedure (see Figure 6.2) since eye-movements were an integral part of the task.

5.2 Asymmetry of the Readiness Potential

(4.5.2, Bashore, McCarthy, Heffley, Clapman and Donchin, in press)

We have initiated a series of experiments designed to (1) characterize the brain macropotentials associated with increasingly complex movements, and

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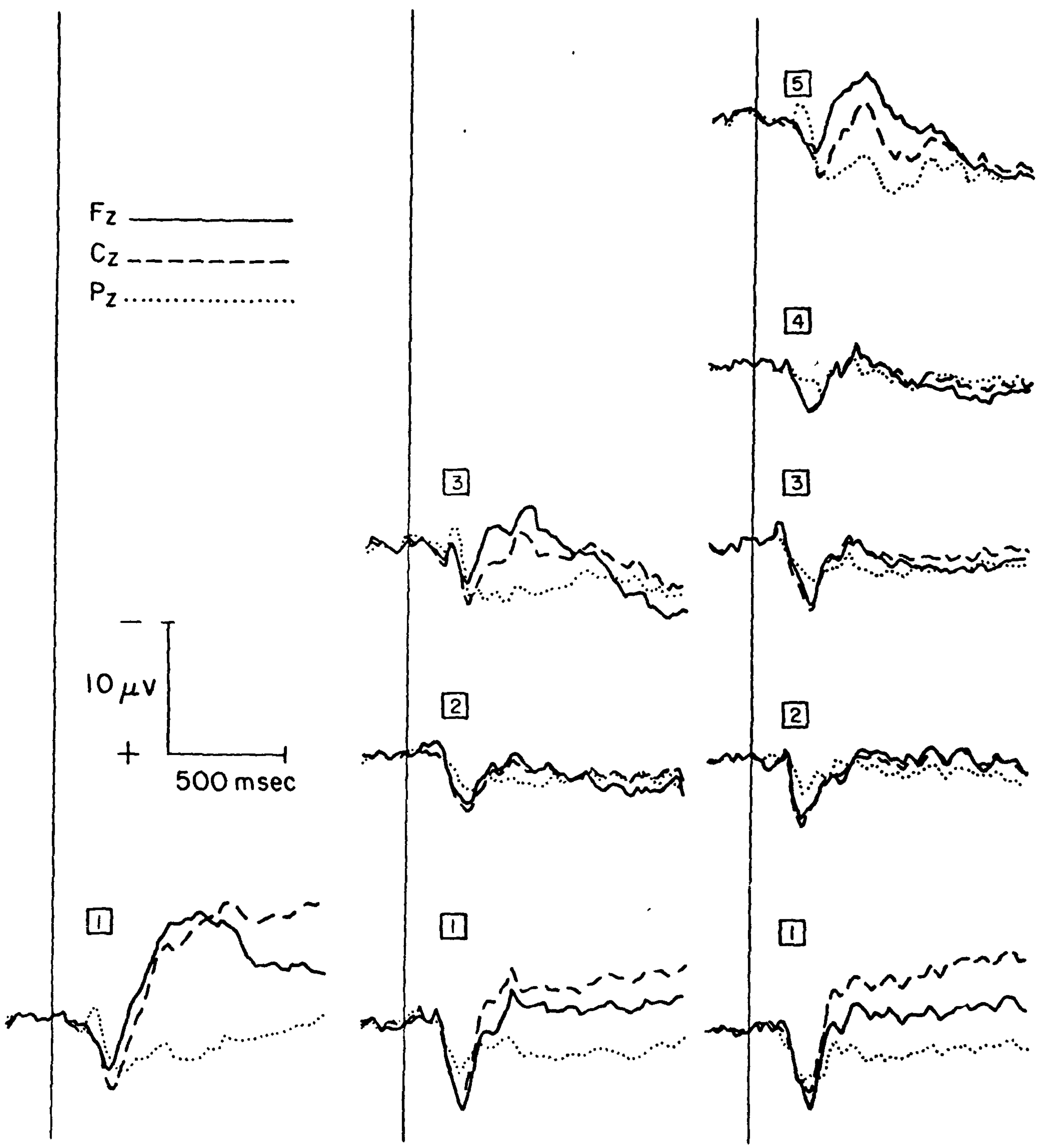


Figure 5.1.1

ERPs elicited by the warning countdown stimuli in conditions in which there were one (left), three (center) and five (right) such warnings.

(2) analyze the relationship between information processing and motor output complexity. A recently completed set of experiments tested Levy and Reid's (1978) model which asserts that handwriting posture is an index of cerebral organization. Briefly, they hypothesize that movement in those persons who write using the noninverted hand posture (hand below the line and pencil tip pointed toward the top of the page) are controlled from the contralateral motor cortex, but in those persons who use the inverted posture (hand above the line and pencil tip pointed toward the bottom of the page) control is from the ipsilateral motor site. We tested this hypothesis in three experiments in which asymmetries in the pre-movement readiness potential (RT) were analyzed. Considerable evidence indicates that the RP, a slow negative change in brain activity measured at the scalp prior to a voluntary movement, is largest over the cerebral hemisphere opposite the moving limb. This asymmetry is consistent with the known neuroanatomical organization of the motor system, and suggests that asymmetries in the RP reflect the direction of control in the motor system. Thus, Levy and Reid's model predicts that in persons with contralateral control of movement (i.e., noninverted-writers) the RP will be larger over the hemisphere opposite the moving limb; but in those persons with ipsilateral control (i.e., inverted-writers) the RP will be largest over the hemisphere on the same side as the moving limb. Subjects, indentified on the basis of handedness and handwriting posture, were required to execute a number of different self-paced movements (e.g., squeezes, writing the word "he" or "hand", dot connecting). The RPs recorded over the sensorimotor area (scalp sites, C1' and C2', approximately 4 cm lateral to Cz along the interaural line) prior to squeezing or writing are shown in Figures 5.2.1 and 5.2.2). As is

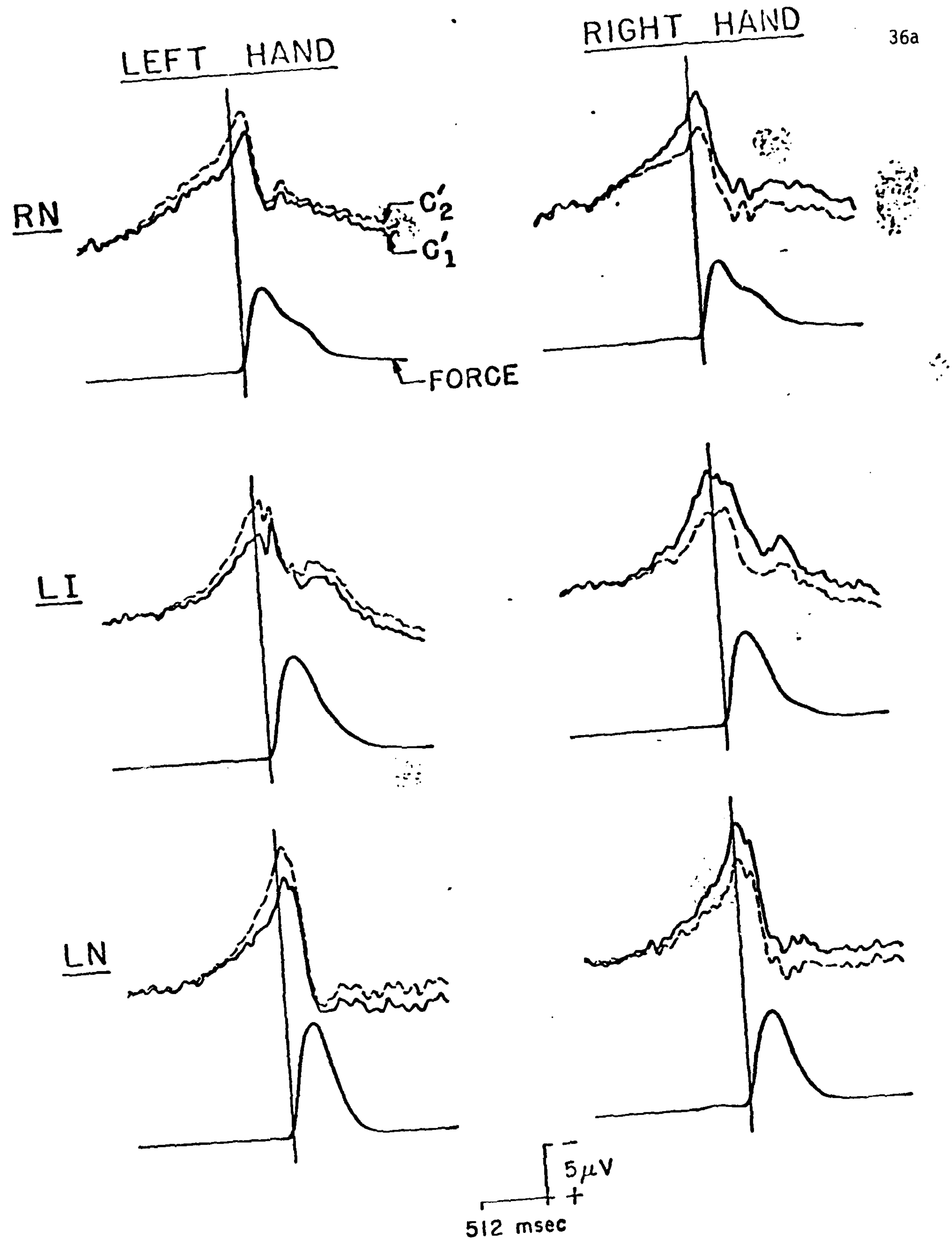
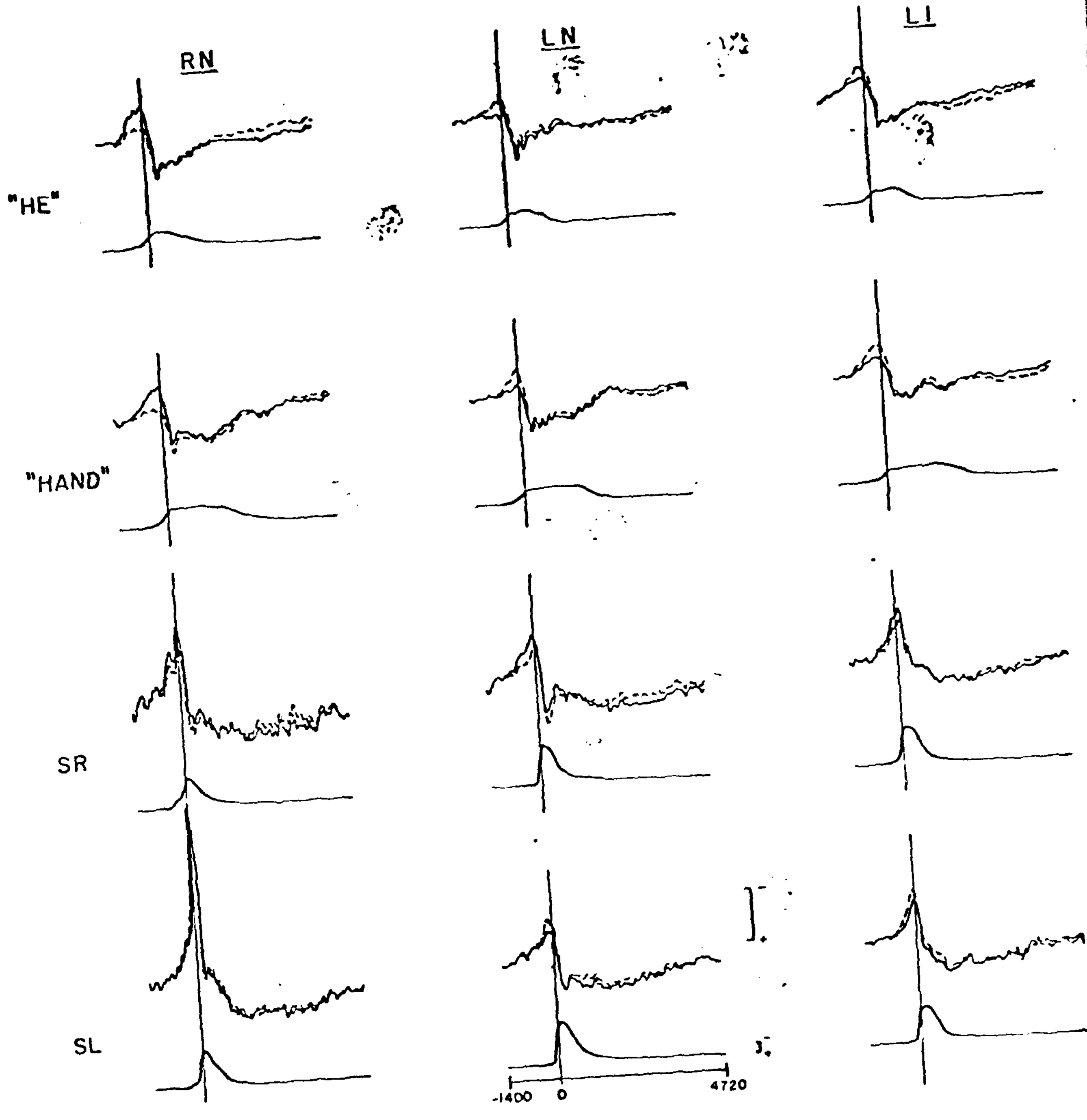


Figure 5.2.1

R = Right handed; L = Left handed; I = Inverted handwriting; N = Non-inverted Handwriting



Fi;ure 5.2.2

Writing He and Hand (top); Squeezing (bottom) evident, the RP is larger over the contralateral scalp site in each group prior to both movements. These data fail to confirm Levy and Reid's hypothesis. However, a small proportion of left-handers (approximately 20%) did produce ipsilaterally larger RPs in the handwriting, but not in the squeeze, condition. The RPs of one such subject are shown in Figure 5.2.3. This finding is very interesting in that to our knowledge it represents the first such demonstration in the literature of such an asymmetry. Tests of Levy and Reid's model using reaction time procedures have produced conflicting results and, consequently, are difficult to interpret.

These experiments are considered to be "baseline" experiments in that they are designed to characterize the brain potentials associated with relatively simple movements. Our research plans include study of the movement-related potentials generated prior to and during increasingly complex movements that require, for example, smooth or brisk movements to goal points, processing of stimulus input signaling changes in goal-directed movements, and the acquisition of complex skilled movements. Further, we intend to study macropotentials associated with voluntary and involuntary movements so as to develop techniques for differentiating these two classes of movements. Comparisons of increasingly complex uni-manual and bi-manual movements will also be accomplished with the same goal.

5.3 N400 and Semantic Distance

The intent of the present experiment is to investigate ERP manifestations of semantic distance processing. Subjects are presented with a category prime (bird or mammal), followed by a word that either is or is not an exemplar of that category. For affirmative responses, semantic

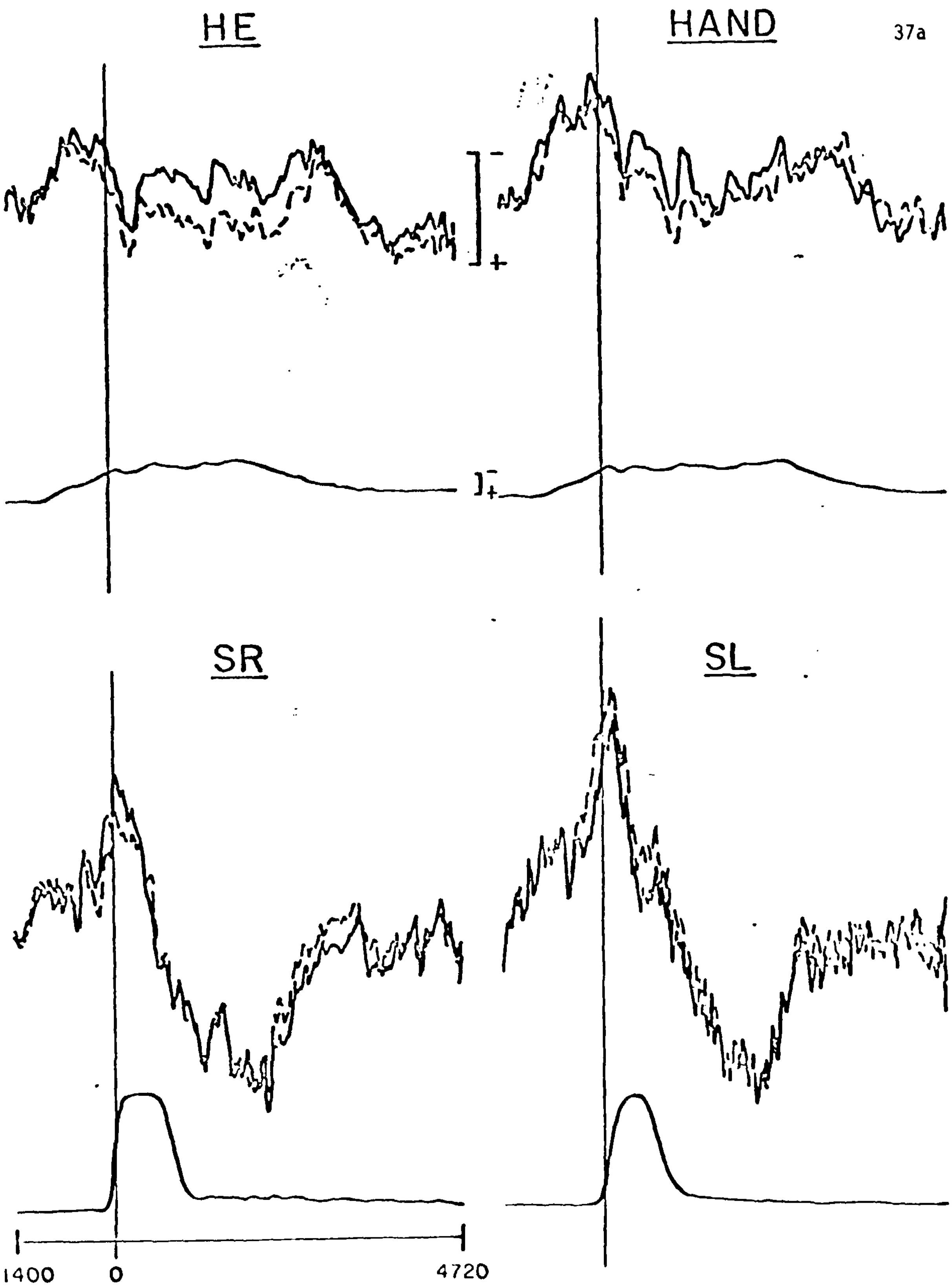


Figure 5.2.3

distance is defined as a function of the degree of "typicality" of the exemplar of the category. Thus, a robin is a "better" bird than a chicken. For negative responses, semantic distance is a function of the amount of features shared by members of the differing categories -- mammals share more features (living, etc.) with birds than do metals. Based upon previous work using congruous/incongruous sentence endings, it is predicted that the amplitude of the N400 component of the ERP might vary as a function of the degree of semantic distance as quantified with multidimensional scaling. The latency of the P300 component of the ERP is also expected to shift as a function of degree of semantic distance for true responses, and as an inverse function of semantic distance for false responses, (based upon previous RT data in this area).

6. Methodological Contributions

In parallel with our experimental research, we continue to address two particular methodological problems that have imposed difficulties in recording and interpreting our ERP data. One concerns the analysis and joint representation of latency, amplitude and electrode data. The second concerns the contamination problem related to eye movement artifacts.

6.1 Vector Analysis

While the latency of ERP components represents an important variable of interest, with a clear theoretical interpretation, there exists considerable methodological problems concerning how this variable should be estimated and represented, particularly since component latency may vary across electrodes and peak latency may represent different information from other latency variables (i.e., latency of onset). The principle of <u>Vector</u>

Analysis which we have developed is based upon the assumption that valuable latency information is represented in the relative amplitude of a given component across the three electrodes, Fz, Pz, and Cz. Vector analysis provides a graphic portrayal of the evolution of a given component (e.g., P300) over time and across electrodes.

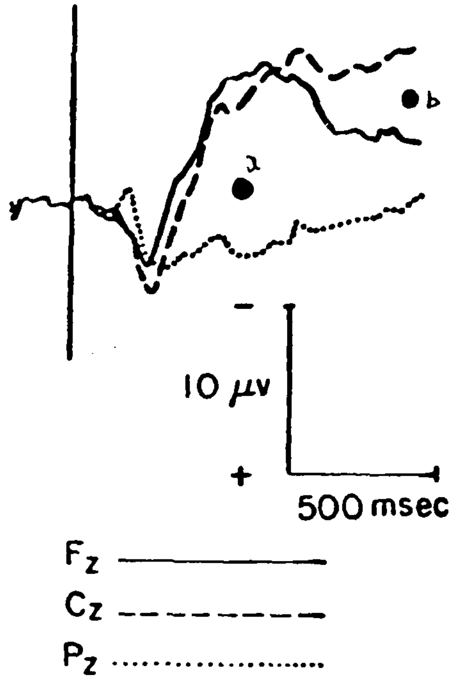
A given component at a given time point is represented by a point in a polar coordinate system defined by three radial axes (Figure 6.1.1.). The three axes represent the relative contributions of Fz, Pz, and Cz to component amplitudes. The radial axis then defines the angle of the vector. Its magnitude is defined by time with T at the center and equal time units radiating outwards. The absolute amplitude of the component is indicated by the size of the symbol representing each point in the vector space. The waveform in Figure 6.1.1, taken from Experiment 5.1 provides an example. At the top, the waveform of the three electrodes are presented. The vector at the bottom depicts the evolution of the waveform from a prominant Fz and Cz component, to a major Pz component at Point a (800 msec), to a vector that provides greater negative weighting at Cz at Point b (1400 msec).

In addition to its clear value as a graphical representational technique, we are now working on analytical methods which will allow us to use the technique for representing vectors of obtained waveforms as linear combinations of idolized component vectors (e.g., P300, N200) whose orientation can be precisely specified.

6.2 A Procedure to Correct ERPs for Eye-Movement Artifacts

A method of correction for eye-movement artifacts has been devised (eye-movements correction procedure - EMCP). Eye-movements are one of the

SLOW WAVE AND CNV



VECTOR ANALYSIS

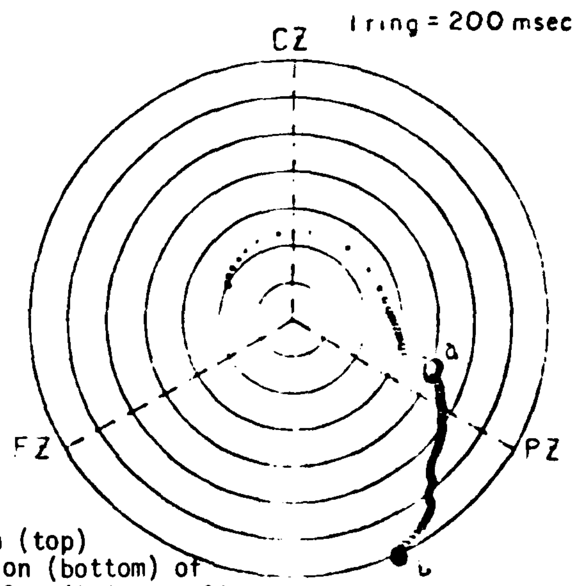


Figure 6.1.1

ERP time representation (top)
and vector representation (bottom) of
data shown in Figure 5.1.1 (left panel)

most important source of artifacts in ERP researches. To eliminate these artifacts, commonly, trials where large eye-movements are present are rejected from the computation of ERPs. This method, however, is not completely satisfactory because (a) sometimes eye-movements are inherent to the task, (b) some eye-movement artifacts can still be present, (c) trials with eye-movements can be of interest, (d) "blinker" subjects are rejected from the experiments, and (e) the experiments must be designed with a "redundant" number of trials.

EMCP corrects for the effect of eye-movements (detected by EOG) computing a correction factor based on the variance not related to the event, both of the EOG and of the EEG trace. The correction factor is computed over all the trials. Separate correcting factors are computed for blinks and saccadic eye-movements (identified by means of their frequence), and for each scalp electrode, experimental session, and subject.

A series of statistical tests showed that EMCP provides a better approximation to a "true" ERP than a "random" correction based on the EOG trace, or ERPs computed using a "liberal" selecting criterion for eye-movements. EMCP also decreased the differences between averages computed over trials with large eye-movements and with small (if any) eye-movements. Application of EMCP to the experimental data collected in Experiment 5.1 improved the results relevant to traditional techniques for dealing with eye-movement artifacts.

In conclusion, EMCP has proved to be a reliable and valid technique for correcting eye-movement artifact, when a very "strict" selecting criterion for eye-movement artifacts is not applicable.

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