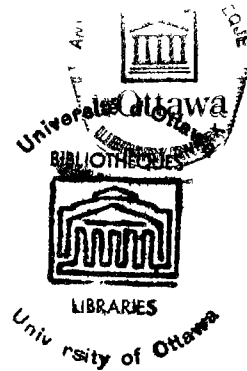


Electrophysiological Correlates of  
Human Concept Learning

Donald T. Stuss

Thesis presented to the School of Graduate Studies  
of the University of Ottawa as partial fulfillment  
of the requirements for the degree of Doctor of  
Philosophy.



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## CURRICULUM STUDIORUM

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## ABSTRACT

### Electrophysiological Correlates of Human Concept Learning

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Evoked potentials were evaluated during a concept learning task wherein each of eleven male subjects, mean age 28.8, had to discover along which of five informational dimensions (e.g., shape, color or number of shapes) they should sort a block of visual stimuli. The subjects made hypotheses as to the possible sorting criterion and were given auditory feedback as to the correctness of the response. After approximately ten trials the criterion was abruptly changed, and a new trial and error learning sequence was thereby initiated. Prior to analysis, the evoked potential measurements across each block of trials were grouped according to five hypothetical learning stages, defined operationally by the feedback stimuli: "preinsight", "insight", "confirm", "overlearn" and "false feedback" (the abrupt concept change).

In addition to the Experimental learning condition, two other conditions were designed to control for other than learning effects. In the Known Concept control, the subject was informed what was the correct criterion to sort the information. The Distraction control required the subject to perform a moderately difficult serial subtraction task. In both controls, the auditory feedback stimuli were manipulated to parody the five hypothetical learning stages.

Significant attentional-intentional differences were noted. In addition, in the Experimental condition, the evoked potential to the feedback stimuli contained a definite late positive wave, occurring with a mean peak latency of 647 ms, that was termed the "P<sub>4</sub>" to distinguish it from the earlier P<sub>3</sub> wave (mean latency = 355 ms). Both the P<sub>3</sub> and P<sub>4</sub> waves were larger in preinsight, insight and false feedback trials, especially when the subject was experiencing difficulty with the learning task. The scalp distributions of the two components were, however, distinctly different, the P<sub>4</sub> being of greater amplitude in the parieto-occipital regions.

It is possible that the P<sub>3</sub> and P<sub>4</sub> waves are electrophysiological signs of separate aspects related to the learning process. The P<sub>3</sub> appears to reflect the appreciation of feedback information, as if confirming or rejecting set hypotheses. The relatively new P<sub>4</sub> may be an index of the utilization of this feedback information, and in this sense may be a true "learning" wave.

## CHAPTER I

### Review of the Literature

#### Introduction

The study of psychological processes may be, and has been, approached from widely diverging viewpoints. One method which has risen to prominence in the last decade or two has been the use of evoked potentials; i.e., measurements of change in the electrical activity of the nervous system, generally the cerebrum, that are elicited by a physical stimulus or psychological event.

Since evoked potentials are normally recorded from the scalp, they are difficult to decipher because of the background electroencephalographic (EEG) activity. It is necessary, therefore, to use techniques such as time-locked stimuli and signal averaging to improve the signal-to-noise ratio. An excellent review of the techniques and problems of recording human average evoked potentials has been presented by Picton and Hink (1974).

The value of evoked potentials is that different components may be affected in varying ways by at least three levels of psychological processes: the properties and qualities of the stimulus-sensation; attentional and/or intentional engagement; perceptual and/or cognitive processing.

In general, an abrupt stimulus such as a sound will elicit evoked cortical responses that may be broken down into early (0-8 ms after stimulus onset), middle (8-50 ms), and late (50-250 ms) components (Picton, Hillyard & Galambos, in press-b). Of these, only the late components, termed the vertex potential, appear to have any relation with higher order psychological processes such as attention. These series of late waves are labelled, at least for the auditory evoked potential, P<sub>1</sub>, N<sub>1</sub>, P<sub>2</sub> and N<sub>2</sub>, with "P" indicating positive electrical valence in relationship to baseline, and "N" negative. Their respective average latencies following stimulus onset are 50, 100, 170 and 250 ms respectively (Picton & Hink, 1974).

There are two other well-defined evoked potential results, not greatly influenced by the actual physical aspects of the stimulus, but more reflective of subjective variables such as decision-making, perceptual processing, expectancy, and meaning. These two measures are the late positive P<sub>3</sub>, or P<sub>300</sub>, wave, and a slow negative potential shift, most commonly termed the Contingent Negative Variation (CNV).

Evoked potential measurements have already been applied to psychological problems such as the effects of stimulus probability, effects of variation in the physical characteristics of the stimulus, and the electrophysiological correlates of perceptual discrimination tasks. Very little has been accomplished with more complex tasks such as concept learning. The possible theoretical and practical implications of such research, however, suggest that such an approach would be fruitful. The

literature review, although not always directly related to the problem of concept learning, will reveal that this is a viable area for experimental study.

This research had as its purpose the experimental study of the electrophysiological correlates of human concept learning. Its hope was to find significant objective electrophysiological indices of the learning process as operationally defined by the experimental task.

#### Human Concept Learning

This selective review of human concept learning is not intended to serve as a theoretical basis for the purpose or design of this research. Rather, the cognitive process as seen by certain theorists will hopefully serve as a backdrop against which the electrophysiological results may be viewed.

One of the earliest psychological treatments of the cognitive process was presented by the Gestaltists, who claimed that almost all learning was insight and understanding (Köhler, 1947, p. 341). Insight, which was equivalent to understanding, was defined as an "awareness of causal relations among mental facts, {and} largely contributes to the way in which mental activities take their course". (Henle, 1971, p. 432).

The problem was well defined. The material consists of a problem, and certain facts. The problem is a situation in which something

must be changed so that the difficulties disappear and the problem is solved (Köhler, 1969, p. 134). Facts and past experience are helpful, but not necessary. Memory plays the same role of helper. None of these, however, can explain the understanding of a present relationship (Köhler, 1969, p. 140).

Although Köhler stressed that the concept of insight was descriptive and not a new mental faculty, his explanation stressed that insight is an active process (Köhler, 1969, pp. 152-153), and that the unclosed organization tends to bring pressure to closure, by means of selective recall (Henle, 1971, p. 184).

In a sense, there are three genres of understanding. One is the complete and sudden insight, the "AHA" experience. This requires active mental work as a preparatory agent, the true insight coming in moments of seeming passivity. The second type of insight is a trial and error approach, best described as the establishment of a plausible hypothesis which is accepted or rejected as bringing an awareness to the problem. These are a series of small, partial insights resulting in gradual learning. The third type is a combination of the first two (Hill, 1963).

Common experience confirms the Gestaltist description. Although it is a description, it does stress that learning is active, and that it often entails a testing of plausible hypotheses as a means of achieving the correct solution.

A study which used a testing procedure with many similar qualities to the task used in this dissertation discussed concept attainment from a cognitive viewpoint (Bruner, Goodnow & Austin, 1956). Their task consisted of eighty-one cards, which varied along four dimensions: colour, shape, number of shapes, and number of borders. A concept was attained by grouping the cards into a particular set of attributes, such as all cards possessing the same number of figures and borders.

The Harvard researchers noted that there appeared to be four selection strategies in concept formation. Simultaneous scanning keeps all possible combinations in mind simultaneously, while trying to eliminate as many as possible with each card selection. Focus gambling requires taking a guess, and betting (hoping) that it will pay off. A third strategy is conservative focusing, in which a correct response is kept as a focus point. The possibilities are narrowed by reverting to the qualities of the focus card as a reference point. Finally, successive scanning occurs when the subject makes a hypothesis, and then verifies or rejects the hypothesis on the following trials.

This dissertation does not deal with actual cognitive strategies. However, it may be of some relevance to describe possible electrophysiological differences in the light of this knowledge.

A related model is the Hypothesis (H), or noncontinuity, theory proposed mainly by Levine (Levine, 1966; Gholson, Levine & Phillips, 1972), which has as its basic tenet that choice responses made during a discrimination learning task (similar to the one used in this research) are organized by hypotheses established by the subject.

Levine noted that, in general, adults and elementary school children were very systematic in their approach. Two basic types of strategy systems were used in making hypotheses. The stereotype approach was a stimulus preference, or a set mode of response even in the face of incorrect feedback, generally seen in young children. Establishing some type of strategy in making hypotheses was the systematic mode of adults.

When a subject does respond according to a strategy, it seems he maintains his hypothesis when given positive feedback after his response, but rejects and resamples other predictions without replacement. The subject also seems to be storing the information of the present trial, summing it with previous results, often rejecting more than the present hypothesis.

An important corollary is that the subject receives more information, rejects more possibilities and consequently learns more effectively when given correct feedback than when given incorrect. "A wrong, with the consequent need for recoding, produces three disadvantages relative to the effects of right. The recoding requires time, the translation can be incomplete, and the material first coded may not be completely erased." (Levine, 1966, p. 332).

If wrong, he must recode, while if correct, he only needs to use material just previously coded. This stands in contrast to others such as Bower and Trabasso (1963) whose models suggest that learning occurs only with errors.

The H theory implies the following possible applications to the electrophysiological correlates of human concept learning. It, along with the Gestalt insight concept, hints that learning comes mainly with achieving the correct answer. The possibility is that there may be an electrophysiological component corresponding to achieving the correct answer. On the other hand, if evoked potentials merely reflect amount of brain activity, then a smaller response, or no response, would be expected with a correct answer, since less information processing would seemingly be necessary.

Negative feedback may also be related with specific electrophysiological responses for two possible reasons: (1) increased amount of information; (2) the necessity of recoding, or of resetting the hypothesis. Levine (1966) saw the procedure as consisting of a stage of selective coding (i.e., a specific aspect of a stimulus is chosen and remembered as the criterion) that is either confirmed or rejected.

Researchers who search for the underlying neurophysiological components of cognitive processes tend to believe that some tangible evidence of learning would be of more relevance, in the sense that these results could be used to identify and be correlated with psychological descriptions.

Such theories have already been proposed. The common factor is that certain cortical areas are hypothesized to be the main locus for

certain types of functioning. They vary, in addition to their theoretical proposals, mainly to the extent they base themselves on anatomical and neurophysiological facts.

One proposed model of information processing which can be linked to specific cortical areas has been defined by Das, Kirby, and Jarman (1975), who derive their functional-anatomical concepts from Luria (1971).

According to Luria, as reported in Das et al. (1975), three important cortical units play a main role in psychological processes. Arousal and intention are connected mainly with the reticular formation. Occipital, parietal and fronto-temporal areas and related regions are correlated with input, coding, recoding - in a word, information integration. "Thinking", the planning and programming of behavior, is a frontal lobe function.

Cognitive processing is accomplished by distinct analyzers which integrate and synthesize incoming information in basically two types of activity: simultaneous and successive. Simultaneous, or parallel, processing is localized in occipital-parietal regions; successive, or serial, processing is a fronto-temporal function. Although apparently identifiable with a specific cortical area, the synthesizers work together in overlapping zones.

On the basis of these concepts, Das et al. (1975) proposed the following four unit model. Unit one refers to the input, which can vary according to source (sense modality and/or type of receptor) and

means by which the information in this source is presented (simultaneously, or successively). For example, a slide containing all the relevant information for a problem would be visual exteroceptor input presented in a simultaneous mode.

The information is immediately fed into and registered by unit two, the sensory register, which is hypothesized to act as a buffer between input and central processing.

It is the central processor that can be divided into three major components, each corresponding to a specific cortical area: (1) simultaneous processor, specifically located in the occipital-parietal area, processes separate information into whole groups; (2) successive synthesis, whose role is to process information in temporally organized successive steps, has its locus of operation in the fronto-temporal area; (3) the third component, the frontal lobe, alone is responsible for planning, regulating, controlling conscious behavior; i.e., it uses the information coded, integrated and stored by the two synthesizers, and decides on the most appropriate response. The frontal lobe "thinks".

The fourth unit is output, which is dependent upon the task and not input or processor. Thus, the response may be serial or parallel, depending on the response demands.

The connection of an information processing model related to specific cortical area appears to have tempting possibilities with a neurophysiological research design. There are always difficulties, however, in such comparisons. One is the definition and choice of method of

processing. Any individual could choose one or other or both depending on his condition and habitual means of information processing, and the demands of the specific task. This cannot be controlled by response demands, as the mode of processing and response task are easily dissociated.

Walle J.H. Nauta (1971, 1972) proposed a theory of cortical functioning based almost entirely on neuroanatomical data. These ideas, based on the neural associations of the frontal lobe, may suggest models of looking at neurophysiological data.

A very global description of the anatomical results may help understand the theory. The frontal lobe, or prefrontal cortex, is reciprocally related to two main functional aspects of the cortex. The first, basically composed of cortico-cortical interconnections with the parietal and temporal regions, appears to be mainly involved with the processing of visual, auditory and somatic sensory input. Each primary sensory area first sends information to its own adjoining association areas, which in turn projects to either or both the inferior parietal lobule and the cortical half of the temporal cortex. These more complex association areas have direct reciprocal connections with the frontal cortex.

There is an ascending level of complexity and associations. Although the system is basically a linear line of intermediate cortical processing stations, there is evidence that these stopovers add additional neuronal lines, seemingly giving new or more associated information.

They are not, then, mere relay stations; input-transformations probably occur along the way, resulting in some type of rerepresentation in the end-station, the frontal cortex. It is difficult to imagine the form or level of complexity of abstraction or compoundedness of the information at the frontal lobe when even at both the inferior parietal and rostral temporal areas there is evidence of all three sensory modalities.

The second major relationship of the frontal lobe is with the telencephalic limbic system and its subcortical components. Since this present research is mainly concerned with cognitive processing, this is only mentioned.

The reciprocal relationship suggests that the frontal lobe is both a receiver and a monitor-modulator, a sensor and an effector, involved in both perceptual processing and the programming of subsequent behavior. The correct affective response in a situation may be explained by the integrating of internal affective feelings with information given by the external environment. Only in the frontal lobe are both the internal and external milieu from all exteroceptive modalities represented together. It is as if the frontal lobe receives external information, sends plausible means of response to the limbic system to test the affective concomitants, and then decides on a plan of action.

Based on the cortico-cortical connections alone, "the frontal cortex could be interpreted not only as a higher order processing mechanism for visual, auditory and somesthetic information, it could also be capable of modulating earlier stages in the processing of such information". (Nauta, 1971, p. 137). It could also be viewed as a means of pre-

setting either or both exteroceptive and interoceptive processors, perhaps yielding reference points for complex forms of behavior.

In summary, this selective review of theories connected with the psychological and neuroanatomical bases of cortical functioning was given not to uncover a testable model, but to posit certain methods of analyzing the neurophysiological results obtained in this research.

The first suggestion is that different cortical areas play different roles on learning. It is important then to operationally define a learning function and observe various sections of the cerebrum to see if there are corresponding electrophysiological differences. A corollary to this is the possible variation within and across cerebral sections during a longitudinal view of the learning process. That is, are there electrophysiological differences within or across a specific cortical location as a learner makes errors, when he attains the correct answer, or when he overlearns?

The more psychological models point to differences in the methods and systems of information input analyses. Although more difficult to test electrophysiologically, these ideas may be helpful in explaining individual differences. Other proposals suggest positive psychological events occurring during the learning process that may have electrophysiological concomitants. These include the awareness of some type of perceptual reorganization of relationships, the coding of correct responses and resetting and recoding when errors are made, and the relative values of correct versus incorrect feedback.

### Vertex Potential

The vertex potential has been defined in various terms. Davis, Mast, Yoshie & Zerlin (1966) stated that the  $N_1$ ,  $P_2$ ,  $N_2$  and  $P_2$  components were all aspects of the vertex potential. More common usage considers either the  $N_1$  component alone, or the  $N_1 - P_2$  peak to peak amplitude, as representative of this late evoked response (Picton et al., in press-b). Both the physical characteristics of the stimulus, and certain related subjective variables, have been shown to affect this component.

In this present design, the physical aspects of the stimuli will be kept constant except for the difference in feedback frequencies, in which a tone of 1 KHZ will signify correct feedback, and 4 KHZ will stand for disconfirming feedback. Although it has been reported that there is no difference between frequency and the evoked potential (Keidel & Spreng, 1965), it appears that the  $N_1 - P_2$  amplitude decreases with increasing frequency, particularly at higher sensation levels. (Davis, Bowers & Hirsh, 1968; Rothman, 1970). A smaller  $N_1 - P_2$  to incorrect feedback is expected, then, on the basis of the frequency difference.

One of the psychological correlates hypothesized to affect  $N_1 - P_2$  is selective attention. Many studies reported that selective attention to a stimulus increased the  $N_1 - P_2$  amplitude (Davis, 1964; Keating & Ruhm, 1971; Mast & Watson, 1968; Picton, Hillyard, Galambos & Schiff, 1971; Satterfield, 1965; Sheatz & Chapman, 1969; Spong, Haider & Lindsley, 1965; Wilkinson & Morlock, 1967). The possibility of tonic

arousal rather than attention being the psychological correlate was also suggested (Hartley, 1970; Näätänen, 1967; Smith, Donchin, Cohen & Starr, 1970). These studies, in an attempt to alleviate differential preparatory arousal, randomized the presentation of relevant and irrelevant stimuli.

Slow stimulus delivery rates still allowed for the possibility of selective attention (Wilkinson & Lee, 1972). This was confirmed in a study where both the high rate of delivery and level of discrimination difficulty forced selective attention, and resulted in an enhanced  $N_1$  wave. These results were reported for both a click pattern (Picton et al., 1971) and a frequency discrimination task (Hillyard, Hink, Schwent & Picton, 1973). A study that controlled for frequency, and consequently perceptual mechanisms, by using four different frequencies, found  $N_1$  enhancement for an attended stimulus over a non-attended stimulus (Schwent & Hillyard, 1975). Random targets precluded selective arousal. The authors also reported that the  $N_1$  in their study was larger than normally reported, suggesting a reflection of information load. The conclusion to this debate seems to be that the  $N_1$  is indeed an index of finely tuned selective attention, regardless of the effects other states such as arousal may have on it.

Two recent studies had confirmed and refined the description of the vertex potential. Both frequent and random stimuli evoked larger (but not significantly)  $N_1$  potentials if attended than if ignored, but no effects of attention were noted on  $P_2$  (Squires, N., Squires & Hillyard, 1975). This relationship was reversed when the background and target stimuli were of equal probability. Squires, K., Squires & Hillyard (1975)

also reported that confidence in the decision, that is the strictness of the response criterion, resulted in enhanced  $N_1$  only with correct detections of the signal, while a priori signal probability played no role.

The paradigm of this research will manipulate levels of attention. It is expected that the vertex potential, as measured in the  $N_1$  component from baseline, will reflect these differences.

Along with and often growing from the correlation of attention with the vertex potential have been theories concerning its function and origin. The vertex potential was first regarded as a diffuse non-specific response of the cortex (Walter, 1964). Others postulated that the primary projection areas of the different or particular sensory systems were the centres of generation, and as such might be considered as a preliminary processor of sensory input (Ritter, Simson & Vaughan, 1972; Vaughan & Ritter, 1970).

A study specifically related to the interaction among different modalities and the vertex potential could not conclude from its results whether it reflected a diffuse non-specific response or a set of specific responses from different cortical projection areas (Davis, Osterhamel, Wier & Gjerdingen, 1972).

The possibility that these concepts may not be exclusive were touched upon by Picton & Hillyard (1974), even though they were concerned mainly with function. They noted a frontal  $N_1 - P_2$  with attention to a

a signal. The non-signal vertex potential, although similar in topography to the signal  $N_1 - P_2$ , was more prominent at the vertex. They proposed that the vertex potential was a sensory evoked response, the first step in an evoked response to a detected stimulus. It was a reflection of stimulus set, while the later  $P_3$  was an index of response set:

... the  $N_1 - P_2$  complex may represent the activation of neural assemblies involved with the analysis of incoming auditory information, the extent and nature of which is determined both by the stimulus and by the nature of the attentional process required.  $N_1 - P_2$  seems to reflect higher order analysis rather than differential recognition of signals, since the percentage change with attention was approximately the same for both the signal and the standard stimuli. (p. 197).

This idea of the vertex potential reflecting stimulus expectancy was dramatically underlined in two studies in which the amplitude of an evoked potential to a stimulus varied in the direction of the judgment of the stimulus content as opposed to being affected by the actual physical qualities of the stimulus itself (Begleiter & Porjesz, 1975; Buchsbaum, Cappola & Bittker, 1974). The vertex potential may reflect a cognitive decision about the physical attributes of the stimulus, perhaps activated by the memory traces about a specific experience.

The frontal distribution of the vertex potential has been reaffirmed (Johnston & Chesney, 1974; Picton & Hillyard, 1974; Walter, 1964; Weinberg, Walter & Crow, 1970). Although this suggests, in relation with the function, that  $N_1 - P_2$  is a non-specific response only, there still is the possibility that it may reflect specific stimulus attributes "and may well provide information as to how the auditory stimulus is being perceptually evaluated" (Picton & Hillyard, 1974).

The important determinant in answering this question may be the type or complexity of the task. In a process more involved than a perceptual discrimination task, such as the concept learning task of this research, it may be possible that the vertex potential may reflect either, or both, non-specific and specific stimulus processing. This would probably be noted by either differences in amplitude or topography.

#### Late Positive P<sub>3</sub> Wave

In questions concerning higher order psychological functioning such as learning, the P<sub>3</sub> appears to have more relevance as a possible index of these processes. This long latency positive wave, peaking 250-500 ms after stimulus onset, was first noted by Davis (1964) in a discrimination task, followed later by Walter (1965) who noted it after a complex semantic stimulus, and by Sutton, Braren, Zubin & John (1965) who described a late positive wave after a feedback cue which resolved a subject's uncertainty. This wave, alternatively labelled P<sub>3</sub> (Paul & Sutton, 1972), P<sub>300</sub> (Donchin, Kubovy, Kutas, Johnson & Herning, 1973), the late positive component- LPC (Davis, 1964; Nash & Singer, 1974) and the association cortex potential-ACP (Ritter, Simson & Vaughan, 1972), seems to have as its main criterion for elicitation the requirement of some type of perceptual decision. Its source is considered to be endogenous, in the sense that the P<sub>3</sub> reflects the subjective aspects of the stimulus, such as meaning and significance. It is nevertheless time-locked to stimulus onset, when a stimulus is presented.

Certain aspects may be considered part of the basic definition of the P<sub>3</sub>. It appears to be able to be dissociated from earlier components of the evoked potential (Rohrbaugh, Donchin & Eriksen, 1974). Squires, Hillyard & Lindsay (1973-b) noted, for example, that N<sub>1</sub> may be present when no decision is required of a subject, and that P<sub>2</sub> was also distinct from P<sub>3</sub>. N<sub>1</sub> and P<sub>2</sub> also have different scalp distributions, considered to be more anterior than P<sub>3</sub> (Picton & Hillyard, 1974).

P<sub>3</sub> also is independent of the physical aspects of the stimulus (Cael, Nash & Singer, 1974; Harter & Salmon, 1972; Hillyard, Squires, Bauer & Lindsay, 1971; Ritter & Vaughan, 1969; Sutton et al., 1965; Sutton, Tueting, Zubin & John, 1967), although there seem to be differences in P<sub>3</sub> evocation depending on the clarity or ambiguity of the stimulus (Hillyard et al., 1971; Paul & Sutton, 1972; Squires et al., 1973-b; Squires, N. et al., 1975).

When sensory modalities are interchanged, there does not appear to be a large effect on P<sub>3</sub> evocation (Donchin, 1968; Donchin & Cohen, 1967; Donchin & Smith, 1970; Smith et al., 1970). Levitt, Sutton & Zubin (1973) did note a larger N<sub>1</sub> - P<sub>3</sub> in crossed sensory modalities in normal and depressed subjects but not in schizophrenics. Finally, a P<sub>3</sub> can be elicited even with the omission of a stimulus (Klinke, Fruhstorfer & Finkenzeller, 1968; Picton, Hillyard & Galambos, in press-a; Ruchkin, Sutton & Tueting, 1975; Sutton et al., 1967; Weinberg et al., 1970). In general, then, P<sub>3</sub> appears to be connected with higher order processing.

Although research on this late positive component is generally not concerned with concept learning, the studies do relate to psychological states and models which often have some relationship with the learning process. P<sub>3</sub> evocation generally requires an active attentive state, directed toward some form of a target signal (as opposed to background separate stimuli), which has some degree of unpredictability, and that demands some type of cognitive, perceptual or motor response. The main characteristics, then, are attention, probability and task relevance. There is another class of P<sub>3</sub> elicitation which, while not denying the first, reports that the P<sub>3</sub> may also be evoked under the following circumstances: a non-attentive (passive, ignore) state, task-irrelevant, but with unpredictability of the stimulus as an important factor.

The P<sub>3</sub> wave has been defined as being a reactive change of state from high to lower arousal following a response to a significant stimulus (Karlin, 1970; Karlin, Martz, Brauth & Mordkoff, 1971). In this sense, it is a consequence of cognitive processing rather than its index. If this were true, the P<sub>3</sub> would have little value as a sign of higher functioning, being mainly a sign of relaxation. This undifferentiated arousal reaction (a similar concept has been proposed by Näätänen, 1969 a, b) has been refuted (Donchin & Cohen, 1969; Harter & Salmon, 1972).

The methods used to elicit the P<sub>3</sub> are generally guessing paradigms (confirm or deny a priori guess of type of stimulus), or perceptual discrimination tasks. These are often modified by varying signal probability, criterion strictness, payoff etc. The results of these studies have yielded several theories or models.

It had been proposed that the P<sub>3</sub> was present with the delivery of task relevant information, and was related to the effective information content present and to the significance of the stimulus for a subject (Sutton et al., 1965; Sutton et al., 1967). These variables were manipulated by varying the probability of presentation of the relevant stimuli. Less probable stimuli meant more information in each stimuli, and more uncertainty which demanded resolution.

The concept of uncertainty resolution was also proposed by Cael et al. (1974). A P<sub>3</sub> was noted in most decision categories in a signal detection task, leading to the proposal that it was the resolution of any kind of uncertainty that was relevant. However, uncertainty does not appear to be a necessary factor for P<sub>3</sub> elicitation (Donchin et al., 1973).

Probability fits into the same category as an important, but not necessary, factor. The relationship of more subjective aspects such as the subject's attitude are necessary (Tueting, Sutton, & Zubin, 1971). Only when an individual's guess as to the outcome was taken into consideration was it noted that the P<sub>3</sub> always decreased in proportion to the increasing probability of stimulus occurrence. Later research suggested the concept of salience, or subjective meaningfulness, or increased performance criterion as the underlying psychological concept of P<sub>3</sub> (Benson & Teas, 1972; Paul & Sutton, 1972).

A related concept discussed the P<sub>3</sub> as being correlative with confidence and decision certainty. It had been reported that the P<sub>3</sub> was

a sign of the certainty of an affirmative decision (Hillyard, 1969); the  $P_3$  occurred only with "hits" (correct decisions), with enhanced  $P_3$  amplitudes if the signal was easier to detect, or if the subject had a higher criterion for detecting signal presence (Hillyard et al., 1971). When the confidence decision was studied with a more detailed eight-point scale, it was concluded that the  $P_3$  was a confidence wave, with a direct relationship between  $P_3$  amplitude and confidence in that decision, regardless of the correctness of the decision (Squires et al., 1973-b). Contrary to Cael et al. (1974),  $P_3$  was not noted for misses or correct rejections.

The  $P_3$  is not just an index of certainty, however. The lack of a  $P_3$  to correct rejection, regardless of the confidence level, suggested to the authors that the  $P_3$  is a sign of the confidence in matching input with a template or model of the signal. Whether the signal was truly present or not, the matching process occurred. For a rejection or a miss, no matching process was required. Stimulus probability is merely a factor in the confidence decision.

The template matching concept had been previously suggested (Hillyard et al., 1971), and embellished later (Squires, Hillyard & Lindsay, 1973-a). In this latter auditory discrimination study, feedback disconfirming the subject's discrimination choice evoked a significantly larger  $P_3$  than confirming feedback.  $P_3$  is not just wholly dependent upon signal probability, since this did not hold true for all subjects. It seems to be a two stage process, varying inversely with the degree of expectancy or subjective certainty, and directly with the proper template match.

The two stage procedure first has a template-matching stage in which stimulus input is compared to a stored neuronal model formed according to the Sokolovian model. The closeness of the match influences the end decision stage. An individual has an inner criterion level, called a bias, which is set a priori at a specific expectancy that a signal of a certain type would occur. An affirmative decision follows only if both a comparison is made to a suitable standard, and if the stimulus type exceeds the previous bias. Stage two, however, has a ceiling, such that with a very certain high criterion, the  $P_3$  is not large. If this criterion is lowered (lowering the ceiling), and then feedback is given opposite the decision,  $P_3$  is enhanced. The more certain one is of the decision, the smaller is the  $P_3$ .

The problem of ambiguous stimuli, where expectancy is kept quite constant, is another problem. Squires, K. et al. (1975) reported that with ambiguous stimuli, the two-factor theory broke down. Signal probability did not affect  $P_3$  amplitude; or, rather, the importance of the confidence factor was paramount. The absence of a  $P_3$  to correct rejection was reaffirmed, even though it would have been expected on the basis of high confidence and constant expectancy.

Selective attention appears to be another important factor in  $P_3$  evocation and enhancement (Corby & Kopell, 1973; Donchin & Cohen, 1967; Nash & Singer, 1974; Smith et al., 1970). These results have germinated several two stage models of selective attention and information processing (Harter & Salmon, 1972; Picton & Hillyard, 1974; Ritter et al., 1972). These models tend to have more relevance to concept learning.

Picton & Hillyard (1974) offered a model based on Broadbent's (1971) proposal of two types of selective attention. An evoked potential to a detected stimulus would have two aspects. The first (already mentioned in the  $N_1$ ,  $P_2$  review) reflects sensory set and is enhanced with attention. The second component, response set, is the perceptual decision complex as indexed by the  $P_3$ . It entails the matching of attended inputs to a model (template, memory) so that target stimuli signalling a required response could be detected. This complex does not require a stimulus, but could reflect the detection of an omission. This model is obviously similar to that proposed by Hillyard and colleagues:

A reasonable evaluation would then be that the  $P_3$  complex indexes the percepto-motor sequelae of the decision that a certain signal has occurred. Such sequelae could involve the registration of pertinent sensory information in memory, the resetting of perceptual analyzers or an appropriate behavioral response. (p. 197).

Although reported  $P_3$  research appears to suggest that this late positive wave is highly correlated with psychological variables, it is difficult to state which variables, if any, will affect the  $P_3$  in a concept learning task. The problem is that most research concerned itself with perceptual decisions. A few, however, have dealt with or can be connected with the relevance of the  $P_3$  more from the viewpoint of cognitive processes. These can be subdivided into two classes: those concerned with the output signal of a cortical processor, and those interested in  $P_3$  as an index of an intra-cortical processor. In the former are theories of  $P_3$  and mismatch or novelty detection (Hillyard et al.,

1971; Ritter & Vaughan, 1969; Squires et al., 1973-a, -b) and theories of P<sub>3</sub> as index of uncertainty resolution, information delivering or decision making (Donchin & Cohen, 1967; Shelburne, 1972, 1973; Sutton et al., 1965). Other output theorists have reflected more on P<sub>3</sub> as a sign of the amount of activity of a general processor (Friedman, Simson, Ritter, & Rapin, 1975; Smith et al., 1970).

The concept of P<sub>3</sub> as intra-cortical processor points more to the cognitive process than output. Donchin et al. (1973) reported that the amplitude of the P<sub>3</sub> ordered five different experimental guess conditions. P<sub>3</sub> was smallest when stimuli were highly predictable and inalternate, with maximum enhancement to random stimuli. Since the same order effect occurred for both correct and incorrect responses, they suggested that it was not disconfirming feedback that did the ordering (Squires et al., 1973-a) but the amount of processing required. The P<sub>3</sub> wave was proposed as an index of an intra-cortical processor, with the P<sub>3</sub> amplitude directly related to the amount of processing required.

These authors suggested that the processor could be identified by creating different types of processes. Jenness(1972) had already suggested that the evoked potential was not just a correlate of perception, but should be viewed more as a reflection of actual processing. As such, the LPC should be longer during the acquisition of relevant information, rather than in overlearning.

A study of the relationship of P<sub>3</sub> to the cortical learning process indeed reported that in the relatively simple learning of a

prediction task,  $P_3$  was significantly greater during acquisition than for overlearning. Within acquisition trials, incorrect  $P_3$  amplitudes were significantly greater than for correct responses, yet correct acquisition  $P_3$ s were greater than correct overlearn (Poon, Thompson & Williams, 1974).

If the notion that LPC amplitudes reflect the S's involvement in problem solving is accepted, then it would appear that incorrect trials precipitated greater involvement in this activity than correct trials. One might speculate that in the problem solving process the incorrect trials signaled a flaw in the S's hypothesized sequence pattern and a new pattern then needed to be generated. (p. 669).

Correct  $P_3$  merely reflects confirmation of an existing strategy. The fact that correct acquisition  $P_3$ s were larger than during overlearning probably indexes greater problem solving behavior. This study also reflects the relevance of monetary payoff (Paul & Sutton, 1972). Poon et al. (1974) task also had payoff, and in the overlearning process, where the subject was receiving the maximum amount of money, the LPC decreased in amplitude.

The results of these studies introduce an important aspect in the  $P_3$  literature. The interpretation of the psychological significance may vary depending on the type and complexity of task. A cognitive process views the  $P_3$  as subject involvement, or amount of cortical processing. A more perceptual approach would propose a concept such as template matching.

The second major class of research on  $P_3$  is that related to the elicitation of  $P_3$  when the subject is non-attentive, the stimulus is not task-relevant, but there still remains the aspect of the unpredictability

of the stimulus. This class has generally associated the P<sub>3</sub> with the orienting response.

It is often generally considered that when the individual is not paying attention, no P<sub>3</sub> is elicited (Picton & Hillyard, 1974; Nash & Singer, 1974). The first report of a LPC to an unpredictable change while distracted (reading) was given by Ritter, Vaughan & Costa (1968). Later research (Ritter & Vaughan, 1969; Vaughan & Ritter, 1970) concluded that it was the unpredictable change that resulted in the posterior dominant P<sub>3</sub>. Since a similar wave was elicited in either an active or passive situation, they concluded that the P<sub>3</sub> signified a cognitive evaluation of the stimulus significance which occurred with an orienting response and a task relevant judgment. It reflected both orientation and cognitive evaluation.

Roth and his colleagues (Ford, Roth & Kopell, 1976; Roth, 1973; Roth & Kopell, 1973) reported a P<sub>3</sub> under passive or distracting conditions such as ignoring the stimuli or reading a book. Ford et al., (1976) proposed that the P<sub>3</sub> represented the second stage of the orienting response, related to the degree of the significance of the change, and to the degree of mismatch. They also reported two kinds of P<sub>3</sub>: a passive, earlier, P<sub>3</sub>, more uniformly distributed over the scalp, and a more parietal, active P<sub>3</sub>.

Squires, N. et al. (1975), noting the discrepancy between results with clean and ambiguous stimuli, compared active attention and non-attention and discovered that there are two distinct waves that may have confused the understanding of the psychological correlates of the

P<sub>3</sub>. A non-attentive condition elicits a probability dependent wave, tentatively labelled P<sub>3a</sub>, which does not vary with the task. It comes relatively early as a sharp positive wave between 220-280 ms, is evoked by less frequent stimuli, and its amplitude is inversely related to stimulus frequency. In an attentive state, a P<sub>3b</sub> was also evoked, which was dependent mainly on stimulus frequency, but also on the relevance of a task. The target stimulus always evoked enhanced P<sub>3s</sub>, even with equal probability.

These results appear to resolve the apparent conflict of the attentive versus non-attentive P<sub>3</sub>. There exist at least two types of P<sub>3</sub>. P<sub>3a</sub> reflects the orienting reflex, is evoked by any change, attended or not, and thus appears to be an index of mismatch to the background stimulus. "In this interpretation, P<sub>3a</sub> would index a basic sensory mechanism which registers any change in a background stimulus, perhaps by means of mismatching a specific neural 'model' (Sokolov, 1963) established by repetition of the background." (Squires, N. et al., 1975, p. 399). P<sub>3b</sub>, on the other hand, is noted in an unpredictable shift to a repetitive stimulus, under conditions of attention.

One now apparent difficulty in comparing P<sub>3</sub> results is that many types of P<sub>3s</sub> may exist. Possibly another type of P<sub>3</sub> was reported by Courchesne, Hillyard & Galambos (1975). Against background stimulus representation, rare stimuli were presented which, in different conditions, could be task relevant (control) or irrelevant. In addition, the irrelevant stimuli were either easily recognizable, or had maximum novelty effect.

The results corroborated the importance of unpredictability and attention. They also noted that the very novel task irrelevant stimuli had a P<sub>3</sub> significantly greater than even the counted rare stimuli, and that it was present even when active attention was being paid (count task relevant). Topography differences suggested that very novel stimuli were situated centro-frontally, and became more posterior if either counted or if they became more predictable. Counted stimuli were maximum parietally.

The use of extremely novel stimuli to elicit P<sub>3</sub>, and its presence even during attention, suggests that this novel P<sub>3</sub> is a different phenomenon from others previously reported. One theory offered by the authors is that the difference lies along a dimension of ease of recognition. Stimuli that are easy to recognize result in a more posterior P<sub>3</sub> while a novel P<sub>3</sub> requires frontal evaluation.

There are some indications that the latency of the P<sub>3</sub> may be a relevant factor in understanding its psychological significance. A more difficult task had a P<sub>3</sub> with a significantly longer latency than an easy task (Ritter et al., 1972). Confirming feedback yielded P<sub>3</sub>s with a shorter latency than disconfirming feedback (Squires et al., 1973-a). It was suggested that this could have been due to a greater expectancy bias, in the sense that a highly expected stimulus required less analysis of information. It was also proposed that the incorrect feedback had a longer latency since it reflected matching against a list of models, from most to least expected. In an auditory discrimination task, latency increased in proportion to the loss of confidence in the decision.

Perhaps of more relevance to the significance of the P<sub>3</sub> is its scalp topography, since, as Courchesne et al. (1975) hypothesized, it may be that "... the P<sub>3</sub> is not a unitary brain phenomenon, but can be subdivided into distinct varieties which differ both in scalp distribution (and hence in brain generators) and in psychological correlates" (p. 140). Most results note a posterior maximum, generally largest central-parietally (Picton & Hillyard, 1974; Poon et al., 1974; Ritter et al., 1972; Vaughan & Ritter, 1970). Courchesne, et al. (1975) reported that parietal P<sub>3</sub>s were related to task-relevant, counted stimuli, while the frontal P<sub>3</sub> appeared to be more dependent on the unpredictability and unrecognizability of the stimulus, rather than on its task relevance or physical complexity. A fronto-central P<sub>3</sub> related to the orienting response has also been reported (Squires, N. et al., 1975).

It is possible that further components of the evoked potential coming after P<sub>3</sub> may exist. Squires, N. et al. (1975) reported that the P<sub>3b</sub> was part of a decision complex consisting of P<sub>3b</sub> and a slow positive wave (SW) which followed. The SW came only after infrequent stimuli during the attend condition. This SW was positive parietally, and became progressively more negative at the anterior sites. They suggested that the SW may be an underlying process beginning as early as 180 ms after stimulus onset, since N<sub>2</sub> and P<sub>3</sub> became more parietal in decision situations, which elicited this SW. Factor analysis results indicated that the SW was an independent brain process, although somewhat connected with P<sub>3a</sub> and P<sub>3b</sub>. The factor analysis also suggested that while P<sub>3a</sub> was frontal-central, and the SW was positive parietal and more negative frontal, the P<sub>3b</sub> had a more uniform distribution.

Components later than the P<sub>3</sub> had previously been noted, generally with little explanation. A negative peak (275-400 ms) was noted after P<sub>3</sub> (Smith et al., 1970). Karlin et al. (1971) described and measured an N<sub>3</sub> and P<sub>4</sub> component, related to speed of reaction. N<sub>3</sub> was more negative with slower speed, while P<sub>4</sub> was enhanced positively with faster reaction times. These components were only discussed as part of some general positive effect affecting late components of the evoked potential.

This second positive wave (P<sub>3</sub> counted as first) at a mean latency of 701 ms was reported as an unexpected finding in a signal detection task (Cael et al., 1974). It occurred only in females, and only on hits.

Systematic differences in the N<sub>3</sub> - P<sub>4</sub> components were presented by Jenness (1972). He tentatively suggested that P<sub>4</sub> may be involved in pitch discrimination tasks.

In summary, it is noted that little has been done with evoked potentials and concept learning. It does seem obvious, however, that it is these late components that are related more to the psychological meaningfulness of tasks.

Some comments can be made. Most P<sub>3</sub> research was concerned with perceptual decisions. Will the P<sub>3</sub> elicited in a more cognitive task be similar? Some expectations have already been given. If the P<sub>3</sub> is related to the confidence in an affirmative decision, what will the effect be on P<sub>3</sub> of having reached a solution to a task, and having this solution confirmed. Squires et al. (1973-a) suggested that paradigm differences

had some effect. A guessing task (Tueting et al., 1971), based on pure chance and probability, should be different from a discrimination task in which the decision is based on more information and should be more relevant than probability. It may be suggested that in a concept learning task, the complexity is even greater, and may be reflected in more complex post feedback processing, with greater differences between correct and incorrect feedback.

#### Contingent Negative Variation

Another late component of the evoked potential possibly related to human learning is the Contingent Negative Variation (CNV). Its importance has been underlined by Picton and Hink (1974): "The CNV is particularly applicable to the evaluation of higher nervous function" (p. 39).

To assess its relevance in the field of human learning, this section will review the definition, composition and topography of the CNV, followed by theoretical propositions made by experimenters concerning its associations with psychological functions. A summary of slow potentials and learning will conclude the section.

The CNV was accidentally discovered by Walter and his colleagues (1964), when they noticed a slow wave between two stimuli, the first acting as a conditional or warning stimulus ( $S_1$ ), and the second as an imperative sign demanding a response ( $S_2$ ). The shift was an electrical change

toward negative valence, contingent upon the  $S_1 - S_2$  sequence, and was a variation of the DC level from a neutral baseline. A second label given was the E (expectancy) wave (Walter, Cooper, Aldridge, McCallum & Winter, 1964), and the second imperative stimulus concept was broadened to include decision processes.

This discovery was confirmed by others (Cohen, Offner & Blatt, 1965; Low, Borda & Kellaway, 1966; Rebert, McAdam, Knott & Irwin, 1967). In addition, other types of slow potential changes were defined. Kornhuber & Deecke (1965) noted a negative potential (Bereitschaftspotential) of 5-10 mv arising just prior to the voluntary initiation of a motor act. This "Readiness Potential" (RP) was also unearthed by Gilden, Vaughan and Costa (1966). They defined their motor potential as being composed of four distinct components: (1) a readiness potential (RP), which is a slow rising negative potential beginning up to 1500 ms prior to the response. This RP was maximum at vertex, and was often slightly longer over the contralateral Rolandic cortical area. It could also appear as a positive potential over the anterior frontal areas: (2) a motor positivity, occurring approximately 80 ms before the motor response, and not always present: (3) the motor potential was a more negative inflection growing out of the RP, occurring about 55 ms before movement: (4) the RAP, reafferent motor potential, which was a post motor recovery to baseline.

A prolongation of a CNV past the response was labelled the C wave, or conflict wave (Timsit, Koninckx, Dargent, Fontaine & Dongier, 1970) and was noted most frequently in schizophrenics. A similar negativity was first reported by Donchin (1969). This persistent negativity rebound effect has also been noted in normals (Hillyard, 1969; Weinberg, 1972, 1975), and seems to be connected with feedback, as if Ss were evaluating their behavior, i.e., their response. Lelord, Laffont, Sauvage & Jusseaume (1973) also observed a bilateral, vertex maximal, slow negative wave with a long latency after the movement, usually unaccompanied by a preceding CNV. Weinberg (1972) hypothesized that motivation played a role in persistence of the CNV, with an increased presence if being correct was important to the subject.

Weinberg (1975), using a pattern recognition technique, noted that small CNV-like waves summated to produce these rather long post-imperative negative waves (PINV). He suggested that,

... after feedback, and incidentally also preceding feedback, there are "CNVs" which are generated corresponding to subjective rehearsal of response performance. The subjects may in effect be asking and answering questions of themselves about their own response performance, or perhaps they are simply subjectively repeating to themselves the information (yes or no) which has been presented. (p. 58).

Two other slow potential shifts are known to exist. One is drift, a slower background potential change upon which other slow potentials may develop, and is often considered an artifact (Hillyard, 1973; Klorman, 1974; Tecce & Hamilton, 1973; Weerts & Lang, 1973). This

research will consider drift as a possible important variable, and will draw the baseline to which most amplitudes will be measured along the drift. In addition, baseline offset will be measured (see Experimental Design).

The final slow potential change to be considered is the sustained potential evoked by prolonged sensory stimulation (Picton & Woods, 1975). For example, if a tone is sustained for a period of one sec, a slow negative shift occurs during stimulation, with a distribution slightly more frontally. This sustained slow potential (SSP) appears to be an indicator of cortical processing during perception rather than at stimulus onset. Woods (unpublished data) suggests that there are SSP changes reflecting the perceptual meaningfulness of the stimuli.

Continued research has further defined the CNV. With intervals of four to eight seconds between  $S_1 - S_2$ , there was a biphasic CNV (Klorman, 1974; Loveless & Sanford, 1973; Weerts & Lang, 1973), the first one interpreted as an orienting response, the second as an anticipatory or expectancy response. The first wave is a constant effect of the first stimulus, and decreases over prolonged testing. The second wave, having no inherent time relationship but appearing in anticipation of  $S_2$ , is enhanced over testing.

Tecce (1972) reported that the form of the CNV may vary. Type A has a sharp rise time to maximum amplitude, while Type B has a more gradual slope. Weinberg (1975), who believes that there may be three forms, correlated the wave form with the amount of information processed, CNV

amplitude being inversely related to the amount of information. In his opinion Type B reflects the relevant information being presented in S<sub>1</sub>. He also proposed that accuracy of time estimation is positively correlated with CNV amplitude.

A study using rhesus monkeys (Donchin, Otto, Gerbrandt & Pribram, 1971), noted a TNV (transcortical variation), maximum post-centrally, during a double reaction time task, when a key press was held down between S<sub>1</sub> - S<sub>2</sub>. This TNV had three major peaks between S<sub>1</sub> - S<sub>2</sub> (N<sub>200</sub>, P<sub>400</sub>, N<sub>1000</sub>), followed by a slow positive shift. The N<sub>1000</sub> occurred at basically the same time, regardless of the S<sub>1</sub> - S<sub>2</sub> interval.

If the response followed S<sub>2</sub>, a CNV-like wave appeared between S<sub>1</sub> - S<sub>2</sub>, maximum frontally, followed by a TNV after S<sub>2</sub>.

At first, it was hypothesized that a motor response was relevant to CNV generation (Low, Frost, Borda & Kellaway, 1966). It was soon noted that an overt response was not required for elicitation of a CNV (Cohen & Walter, 1966; Donchin, Gerbrandt, Leifer & Tucker, 1972; Walter, 1965; Wilkinson and Spence, 1973). In general, however, the CNV amplitude is enhanced when a response is required (Irwin, Knott, McAdam & Rebert, 1966; Low, Frost, Borda & Kellaway, 1966). This may be due to summation effect of a CNV and RP.

With a response to S<sub>2</sub>, the CNV negatively terminates in a positive going limb, called the resolution of the CNV, which often goes beyond baseline and becomes positive in its polarity (Bostem, Rousseau, Degossely & Dongier, 1967; Cohen et al., 1967). Some have proposed that

this post-stimulus resolution is the main constituent of the P<sub>3</sub> wave (Donchin & Smith, 1970; Hartley, 1970; Wilkinson & Lee, 1972; Wilkinson & Spence, 1973) or that the P<sub>300</sub> is a reaction to CNV development (Karlin, 1970).

Concerning the CNV resolution alone, Wilkinson & Lee (1972) claimed that CNV baseline return may be a better indication of attention than other evoked responses. Wilkinson & Spence (1973) concluded that CNV resolution is not due to a motor response, or expectancy, but that it is a reflection of a coarse, sensory recognition that a stimulus is relevant. A second CNV would indicate a finer analysis to determine future action. This explanation seems to dovetail with the biphasic CNV explanation of Loveless and Sanford (1973, 1974). Picton and Low (1971) interpreted CNV resolution as occurring with the intrinsic feedback of the learned response as the subject learned.

The CNV-P<sub>300</sub> issue appears to have been laid at rest, concluding in the independence of the CNV and P<sub>3</sub> (Donchin & Cohen, 1967, 1969; Donald & Goff, 1971; Donchin, Tueting, Ritter, Kutas & Heffley, 1975; Eason, Harter & White, 1969; Friedman, Hakarem, Sutton & Fleiss, 1973; Harter & Salmon, 1972; Hillyard et al., 1973).

Although the evidence does seem to indicate the independence of these two components, some comments seem necessary. Those who advocate a CNV-P<sub>3</sub> relationship often describe no visible P<sub>3</sub>. It is possible that their paradigm did not elicit a true P<sub>3</sub> and that sometimes

a CNV resolution may resemble a P<sub>3</sub>. This does not explain why, in paradigms that do have both components, they apparently do not summate (Donchin et al., 1975). Finally, statistical techniques in separating the components may be of dubious validity (Donchin et al., 1975).

CNV scalp topography may be an important phenomenon in indexing functionally different processes in different areas of the brain. Walter (1964) and Low et al., (1966) first stated that CNV was a frontal phenomenon. This concept was expanded (Cant & Bickford, 1967; Cohen, 1969; Walter, 1967), noting that CNV occupied a large area of the frontal cortex, rising in a gradient to maximum amplitude at the vertex, being smallest posteriorly. Although the RP has been shown to be largest on the contralateral side (Kornhuber & Deecke, 1965; Kutas & Donchin, 1974), and to have a specific topographic organization corresponding to the motor cortex (Vaughan, Costa & Ritter, 1968), the CNV in normal Ss is bilaterally symmetrical in amplitude and morphology over the two hemispheres of the brain (Cant, Pearson, Bickford, 1966; Cohen, 1969; Low, Frost, Borda & Kellaway, 1966). This pre-motor CNV symmetry was noted even in split-brain patients (Gazzaniga & Hillyard, 1972), suggesting a bilateral active sub-cortical pacemaker was the predominant generator of CNV amplitude. Asymmetry, if noted, was only a small tendency (Syndulko, 1969). The problem of interpreting the pre-motor CNV is the very possible interaction of CNV and RP (Hillyard, 1973).

Some studies, however, have some distinct CNVs with different perceptual-motor tasks. Avoidance of a noxious stimulus yielded a more frontal CNV than a mere operant S<sub>2</sub> response (Cant & Bickford, 1967).

Jarvilehto and Fruhstorfer (1970) observed a more frontal CNV for an auditory discrimination task than for a motor response. For a visual discrimination task, the CNV was reported to be more posterior than for auditory discrimination (Cohen, 1973).

A lack of correlation with reaction time and prefrontal CNV, compared to central-parietal correlations with some behavioral correlates, led Papakostopolous & Fenelon (1975) to suggest:

... it seems possible that the CNV waveform maps the processing of information under the recording area, the differences in form ultimately being reflected in strength of behavioral correlates... (p. 77).

The scalp distribution of the CNV does appear to be a rewarding area for research into cognitive functioning. Its possible application for this research will be summarized at the end of the section on CNV.

#### Psychological factors

Grey Walter first conceived of his E wave as a cortical primer (1964), later expanding his idea (1967) to see uncertainty, the most important sign of stress, as a main correlate of the CNV. The brain, computer of statistical significance, responds to the presence of information, and decreases with its loss or repetition. Increasing uncertainty, or equivocation of the probability of reinforcement, causes a gradual decline in the CNV. Moreover, the CNV develops over time, as if the brain must take samples of the information before it decides that there is subjective certainty.

Man is a stress-seeking animal, but stress must be mastered or kept within limits. "The frontal lobe mechanisms that are reflected in the

E wave seem to have the function of ensuring that whatever stress we encounter is unlikely to produce a strain that is either unendurable or irreversible" (Walter, 1967, p. 262). If stress becomes too high, the brain opts out.

Low, Frost, Borda & Kellaway (1966) proposed 'conation', or intention to respond, as the main determinant. A third proposal (Cant & Bickford, 1967; Irwin et al., 1966; Low & McSherry, 1968) saw general motivation as the primary determinant of CNV amplitude. Even if the CNV reflected expectation, motivation was a primary factor in its development.

The concept of preparatory set (Loveless, 1973; Loveless & Sanford, 1974) appears to follow Walter's original concept. The fact that there was a good relation between reaction time and amplitude of the E wave led them to suggest that the CNV reflected preparatory set, and also the criterion shift governing the response. However, not all CNVs were indicators of expectancy or anticipation. There also existed the orienting CNV.

Although heart rate (HR) and the CNV were found to be correlated (Lacey & Lacey, 1970), a paradigm (Lacey & Lacey, 1972) which gave either immediate or delayed reinforcement seemingly disentangled the two components. HR correlates with both attention and response intention, while CNV appears to be only response-intention, since it did not appear with delayed feedback. In this sense, it appears to be a preparatory or motor set. Weinberg (1972), by separating the processing of information and expectation of FB, saw the CNV as being primarily related to attention.

Notwithstanding Lacey & Lacey, perhaps the most often proposed hypothesis is that of attention. Low, Frost, Maulsby and McSherry (1968) stated that the intent to perform a response may be affected both by motivation and attention, for if a simple mental task intervened between  $S_1 - S_2$ , CNV amplitude did not increase as in other conditions. McCallum & Walter (1968) noted that, while anxious people had significantly smaller baseline CNVs than normals, both groups had decreased CNVs with distraction, the amount of reduction related to the degree of attention.

The CNV-attention hypothesis is supported by other results, (Ellis, 1969; Näätänen, 1970). Increased CNV amplitudes were reported for the detection of a barely audible  $S_2$  (Low, Coats, Rettig & McSherry, 1967; Rebert et al., 1967), with enhanced voluntary concentration on  $S_2$  (McAdam, Irwin, Rebert & Knott, 1966; McCallum & Walter, 1968) and with positive reinforcement for fast motor responses (Tecce, 1972).

A food reinforcement and deprivation technique using animals (Borda, 1970) led to the conclusion that attention seemed to be underlying correct performance, and that a frontal CNV remained high as long as the S had a high level of performance. In a difficult signal detection task, CNVs were larger for detected signals than for missed signals (Hillyard, 1969; Hillyard et al., 1971), suggesting a relationship of CNV with selective attention.

Other researchers reported larger CNVs with correct judgment (McAdam & Rubin, 1971; Wilkinson & Haines, 1972). On the other hand, similar paradigms yielded no such correlation (Jarvilehto & Fruhstorfer,

1970; Jeness, 1972; Paul & Sutton, 1972). If a task was too difficult, attention was impaired, perhaps due to distraction, and the CNV declined (Delse, Marsh & Thompson, 1972).

In more systematic studies of distraction, Tecce & Scheff (1969) found that, with distraction, either before  $S_1$  or between  $S_1 - S_2$ , the CNV declined in amplitude, although there were no significant differences between different levels of difficulty. They also noted that, when responses were grouped according to reaction time, there was an inverse relationship between RT and CNV, suggesting a common process, attention. Since  $S_1$  and  $S_2$  were never omitted, expectancy was eliminated as a possible correlate of CNV. Motivation was also ruled out, as subjects reported greater effort to respond during the distraction task, and the HR increased. Finally, conation was ruled out, as the subjects did not report an increased intent to respond. The amplitude of CNV appears to be "a sensitive measure of attentional processes in humans" (Tecce & Scheffe, 1969).

Tonic or sustained distraction by irrelevant cognitive activity had the same CNV amplitude-reducing effect (Tecce & Hamilton, 1974), leading Tecce to reiterate his attention hypothesis of CNV development (Tecce, 1972). The relationship between CNV magnitude and attention was proposed to be a positive monotonic one, although not necessarily linear. Arousal, however, has an inverted-U relationship with CNV, so that low levels of arousal are associated with increased CNVs but high levels are correlated with lower CNVs. In a distraction task, CNV declines as HR increases.

Attention is seen as having a steering function, helping to focus on relevant stimuli while filtering out unimportant matters. Arousal is non-selective, being a behavioral energizer and affecting only the intensity of the response. These two components are not necessarily orthogonal, but may interact. Finally, there may be other factors affecting CNV development.

Although this two process model of CNV development appears to have some heuristic value in explaining CNV, it does not consider the HR-CNV dissociation discussed by Lacey & Lacey, in which it seems the CNV does not correspond to attention. Moreover, some of the arguments Tecce has advanced for the two process model may be more parsimoniously summarized by a solitary arousal model, with attention correlating positively with the CNV only on the first part of the U-curve.

Confounding variables make it difficult to accept a relationship of CNV generation with a too simplistic concept. Delse et al., (1972) had already noted that level of difficulty influences CNV amplitude. The influence of levels of trait and state anxiety, stress, ceiling effect and sex interacting with these have led to the conclusion that the CNV is not determined alone by simple factors such as response set or expectancy (Knott & Irwin, 1968; Knott & Peters, 1974; Low & Swift, 1971). For example, as a task became more difficult, females had significant declines in CNV if they responded, but increased on no-response punishment trials (Knott & Peters, 1974), while males showed no significant differences. The mean CNV, however, was not significantly different between sexes. It is difficult to explain this by invoking a ceiling effect.

Rapid reaction time has been said to be the most stable behavioral consequence of the CNV (Hillyard, 1969, 1973), but even it lacks a stringent association. Intra-subject and inter-task variability make it difficult to control all relevant factors. RT research strongly shows the need for stringent replicated designs. A corollary is the fact that what the CNV does represent may be more complex, and that this complexity may obviate any clear relationship of CNV and behavior. The CNV has been viewed (Weinberg & Papakostopoulos, 1975) as a unitary phenomenon modified by local sites, a composite wave made up of different waves converging in different combinations on different sites, or strictly localized generated CNVs.

Studies relating CNV development to learning are few, and often non-direct. Low, Borda & Kellaway (1966), using Rhesus monkeys, noted that a CNV developed during the process of learning to avoid shock. As the animal learned to make a discrimination, the CNV was related only to the meaningful (reinforced) stimulus. When the unreinforced and meaningful stimuli were reversed, the negative shift developed to the former, and decreased for the latter.

It was concluded that the CNV was a correlate of operant conditioning in animals. It developed only in anticipation of significant signals, and was maintained only in the presence of an operant response. This concept developed into the hypothesis of conation.

The possibility of a measure of learning is interesting. The above research, however, gave no indication of the question of the control

of eye movement. Nevertheless, if true, the question of the relationship to learning remains. Is it a sign of learning, or of a learned response, or possibly both?

A problem of motivation and the CNV may shed some light on learning (Borda, 1970). Two independent CNVs were recorded during a food deprivation task. A frontal CNV reached a peak early in training, and was present as long as the monkey maintained a high level of performance. This was interpreted as a sign of selective attention subserved by non-specific thalamo-cortical pathways. A central-dominant CNV decreased in amplitude with overtraining, and appeared most generally after food-deprivation.

Chiorini (1969) also observed different correlations of CNV with learning. In a classical conditioning task on two groups of cats, one group learning a task quickly while the others were non-learners, it was observed that for the learners, there was a greater contralateral slow potential (SP) during conditioning and overlearning. All cortical areas showed decreasing amplitudes during habituation and extinction. The non-learning group had no hemispheric SP differences during acquisition, and the decrease in amplitude occurred only during extinction.

Slow potential changes did appear to correlate with behavioral measures of learning. It was proposed that two or more subcortical systems were operating. Equal bilateral changes for both groups was a diffuse activation, perhaps generated by the brain stem reticular formation, and yielding general levels of arousal. The localized negative increase

seemed to be important for the elaboration and development of the conditioned response, but not for the continuing activity. This probably involved specific thalamic nuclei.

It may be that the correlation of CNV with learning will depend on cortical localization, or specific types of cognitive activity, Rubin & McAdam (1972) that the CNV waveforms over the temporal area were different for a subjectively certain recognized word as compared to subjective uncertainty, while this difference was not seen frontally or centrally. This difference appeared to be related to subjective aspects of memory retrieval.

The correlation of CNV with a specific type of activity was noted by Stamm & Rosen (1972) in a delayed response task using monkeys. Once they had achieved a high level of correct performance there were three distinct frontal slow potential shifts in a temporal sequence, suggesting three processes: expectancy, mnemonic processes, and reinforcement.

Expectancy was noted during the inter-trial interval in anticipation of the first, discriminative, stimulus. This negative shift, although largest prefrontally, was not limited to this area. The elimination of the food reinforcement precipitated a greatly reduced SP for all cortical areas preceding reinforcement, and was not connected with reaction and performance time. These two processes were hypothesized to be mediated by diffuse neuronal processes which involve large cortical areas.

The mnemonic process, preceding the imperative stimulus, was found only in the prefrontal cortex. It was the only SP highly correlated with the level of correct performance. With longer S<sub>1</sub> S<sub>2</sub> delays, it returned to baseline after five seconds, perhaps suggesting short-term memory formation rather than memory stage. It also was not affected by the amount (duration) of information input, although the occipital SP was.

The role of feedback in CNV development may be another factor connecting the CNV with learning. Certain results indicate no significant difference in CNV amplitude if FB is given or not (Rebert, 1972; Rebert & Sperry, 1973), nor did the level of obtaining FB (Rebert & Sperry, 1973). Peters, Knott, Miller, Van Veen & Cohen (1970) suggested that the psychological relevance of the task was more important than the actual FB.

Certain authors see feedback as important. Picton & Low (1971) interpreted their results of CNV prolongation with the increase of importance in FB information as suggesting that the CNV was important to learning. As a subject learned, the response to FB would become smaller, as if the intrinsic feedback of the learned response would cause the CNV discharge. It would be important to further study this suggestion by varying more exactly the relative meaning of feedback. As it stands, pre-FB CNV may be related to anticipation rather than meaning, which is the interpretation offered by Weinberg (1972).

The conclusion to this review is that there does not exist any "proven" connection of the CNV with behavior (Hillyard, 1973), although the possibility exists. The CNV does not seem to reliably predict or be correlated with performance; it seems to occur with a large number of acts: "... it seems premature to conclude that the CNV indexes any selective processes (such as attention) in anticipation of a task signal." (Picton et al., in press-b).

In addition, experimental paradigms have been numerous, and have made generalization difficult. Finally, theories of its generation are complex (Hillyard, 1973; Rebert, 1973; Weinberg & Papakostopoulos, 1975).

Hillyard (1973) precisely summarizes the difficulties and possibilities:

To the extent that different task demands activate different cerebral regions, it may be possible to identify qualitatively different CNV configurations with different psychological constructs. However, if the magnitude of the negativity reflects as crude a measure of neurophysiological processing as total neuronal activity, precise correlations with behavioral parameters are not to be expected. Changes in the detailed patterning of nervous activity which underlies learned improvements in behavior would not then necessarily show up as increases in the CNV. (p. 169).

### Summary

The review of literature has revealed that certain electrophysiological measurements do reflect higher order psychological processes. This fact underlines the possibility that there may be electrophysiological correlates of learning.

Little has been done even to the present time. Thompson, Patterson & Teyler (1972), in their review of the neurophysiology of learning, concluded:

In fact, we still have only the barest outline of the neural correlates of learning. In our opinion, this dearth of data and paucity of substance is due mainly to the failure to utilize the necessary behavioral controls and well-delineated behavioural paradigms. Elegant neurophysiological recording techniques can tell us little about the neural basis of learning unless accompanied by correspondingly sophisticated behavioural techniques. The systematic investigation of brain activity underlying learning necessitates the consistent use of behavioural systems in which the behavior can be accurately measured. Control procedures must be constantly utilized to rule out nonassociative activity in neural responses. The lack of such activity in overt behaviour simply does not preclude its occurrence at neural levels. (pp. 85-86).

The aim of this present dissertation was to devise a learning task which had the following components. The task would be a concept learning problem similar to designs previously used. The learning problem must have tangible results (incorrect vs. correct) that could be correlated with the evoked potentials. The learning process would be defined so that the separate components of problem solving could be analyzed: preparation for problem, presentation of the problem, time for response, expectation of response feedback, and external feedback. Finally, control procedures which hopefully could stringently match Thompson et al's (1972) demands would be designed.

## CHAPTER II

### Method

#### Experimental Paradigm

The basic objective of this research was to measure the electrophysiological changes occurring during human learning. The experimental paradigm devised for this process was derived from the Wisconsin Card Sorting Task (Grant & Berg, 1948) utilized by Milner (1963) in her study of frontal lobe dysfunction.

Sorting tasks require a selective response to one aspect among many possibilities presented to a subject. Stimuli incorporating several different informational cues (e.g. colour, shape, etc.) are presented one at a time and the subject is required to sort or code the stimuli along one of the selected informational dimensions. The specified code is preselected by the examiner and is initially unknown to the subject. The subject must therefore make hypotheses as to the criterion ("criterion", and "concept" will be used interchangeably) by which he should sort the experimental stimuli, respond according to these hypotheses, and then receive feedback as to the correctness of his response. Through such a trial and error procedure, the subject is thus able to learn the required criterion. After a selected number of experimental stimuli, the required sorting principle is shifted without warning so that the previous code is wrong. The subject must then repeat the procedure of trying to determine the correct underlying criterion.

This task includes, therefore, the following characteristics:

(1) a trial and error approach to learning the correct answers--this may be best described as the establishment and testing of behavioural hypotheses; (2) the use of feedback to modify incorrect responses, or to act as reinforcement of correct responses; (3) the necessity of altering established modes of response.

In this research slides were used instead of cards (Figure 1). Each slide contained and varied on all of the following four dimensions: shape, the number of shapes present in the slide, the colour of the shapes, and a number in block letters in the middle of the slide. Each of these four dimensions had four possible variations. One of the following four shapes was in the slide: circle, square, triangle, cross. The number of the shapes was varied from one to four. The colour of the shape(s) was red, blue, green or orange. Finally, in the centre of each slide was a written number from one to four. The sum total of possible combinations was  $4 \times 4 \times 4 \times 4$  or 256. Two sets of 256 slides were prepared so that any one combination of variables on a slide had two possibilities of being presented. A fifth dimension of the task was mathematical operations, which demanded a response to a result of the absolute difference between the number of shapes and the written number. If the written number was four and the number of shapes was three, or vice-versa, the answer was one. There were four possible responses--zero, one, two, and three--the probability of one and two being slightly higher than the probability of zero and three.

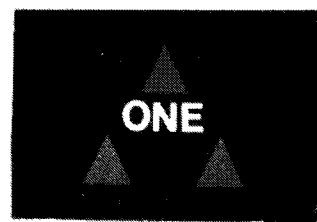
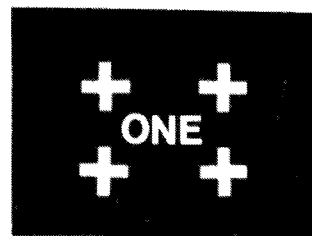
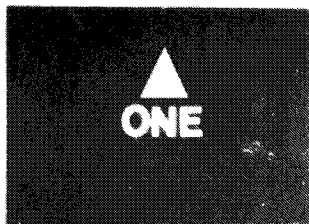
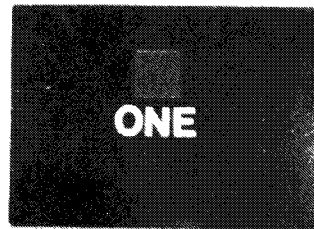
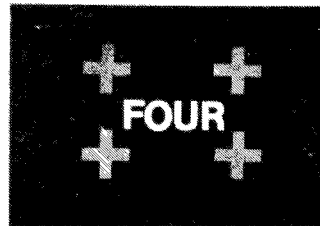
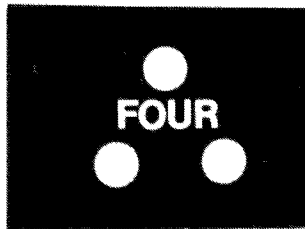
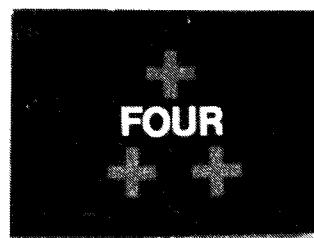
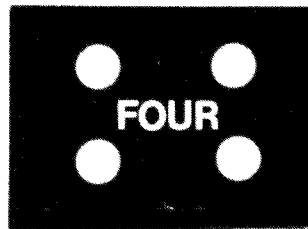


Figure 1

## Examples of Slide Stimuli

These samples of the visual stimuli presented in the concept attainment task show how the slides varied in shape, colour and number of figures, and in the word in the centre. Variation in slide colour in these examples are due to reproduction difficulties, and were not present during the experimental presentation.

SLIDE STIMULI EXAMPLES



The presentation of one slide and its concomitant warning and feedback stimuli was called a trial. A series consisted of a number of trials subdivided a priori according to one of the five different criteria. An average of 10 trials (range from 9-12) constituted each series.

The 512 slides were arranged in four 140 slide carousels, with the stipulation that identical slides could not be consecutive. Within the carousels the slides were divided into series and coded for the appropriate response for each series criterion (see Table 1). The ordering of series within the carousels was random except that the same concept could not occur twice in a row, nor could any carousel end in a concept with which another carousel began.

Four buttons were used for the subject's response, one for each finger of the right hand. The buttons were numbered from one to four beginning with the index finger. Each subdivision of each concept had a specific relation to each response button, shown schematically in Table 2.

In order to standardize trial presentations so that evoked potentials could be averaged, each slide was presented according to a fixed time schedule (see Figure 2). A trial began with a positive electrical pulse serving both to begin the sweep for evoked potential averaging and to activate a counter of the number of trials. Approximately 300 milliseconds after the beginning of the synchronization trigger, a

Table 1

Arrangement of Slide Stimuli According  
to Concepts Within Carousels

Concept	Carousel			
	I	II	III	IV
1	N ( 9)	O (10)	C (10)	O (11)
2	# ( 9)	F (10)	F ( 9)	N ( 9)
3	C (12)	C ( 9)	N (10)	C ( 9)
4	# (10)	N (11)	C ( 9)	O (10)
5	O (11)	# ( 9)	# (10)	F (10)
6	F ( 9)	O ( 9)	N (11)	# ( 9)
7	N ( 9)	# (10)	F ( 9)	O (11)
8	F (10)	C (12)	O (11)	F ( 9)
9	O (11)	F (10)	# ( 9)	# (11)
10	C (11)	N (11)	N (10)	C ( 9)
11	O (10)	C ( 9)	O ( 9)	N ( 9)
12	F ( 9)	# ( 9)	N ( 9)	F (10)
13	N ( 9)	N (11)	C (10)	
14		# (10)		

NOTE. The number in brackets indicates the number of trials constituting that specific series.

N = Number of Shapes

C = Colour

# = Written Number

O = Mathematical Operations

S = Shape

Table 2

Relationship of Response Button to  
Dimensions Within Each Concept

Corresponding Concept	Response Button			
	One	Two	Three	Four
Colour	red	blue	green	orange
Shape	circle	square	triangle	cross
Number of Shapes	1	2	3	4
Written Number	4	3	2	1
Mathematical Operations	0	1	2	3

Figure 2

## Timing of Presentation of Stimuli for Each Individual Trial

The beginning of the sweep was experimenter initiated. Presentation of the warning click, slide onset and offset, and feedback toneburst was time-locked according to the timing schedule in the figure. The example of the corresponding electrophysiological changes are taken from an Experimental Preinsight sequence, measured at CZ, with replication. Subject: G.C.

WS = Warning stimulus

S on = Slide on

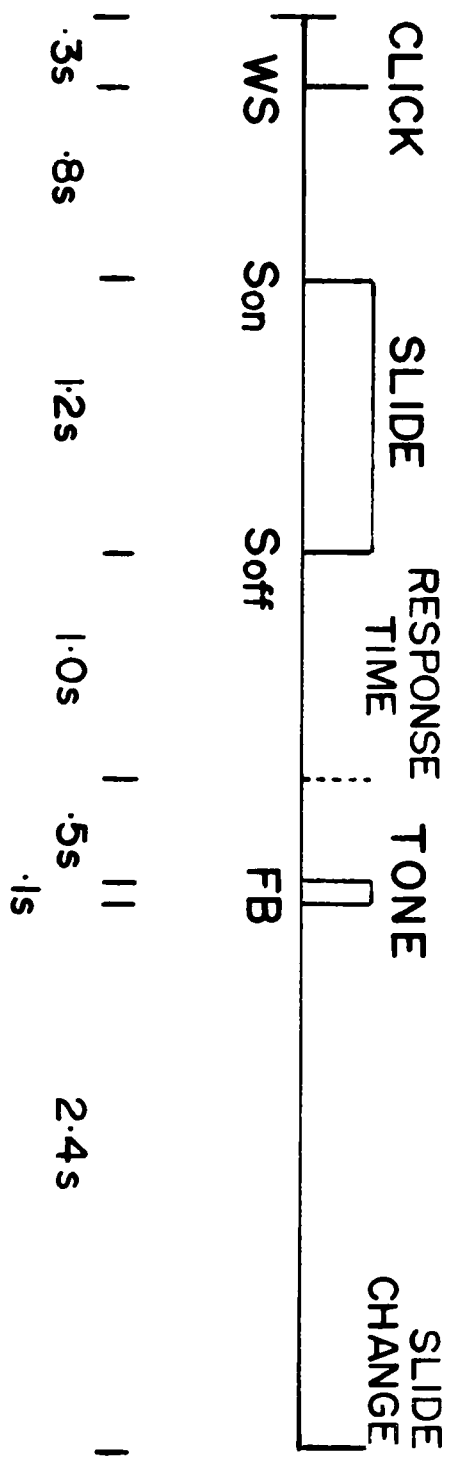
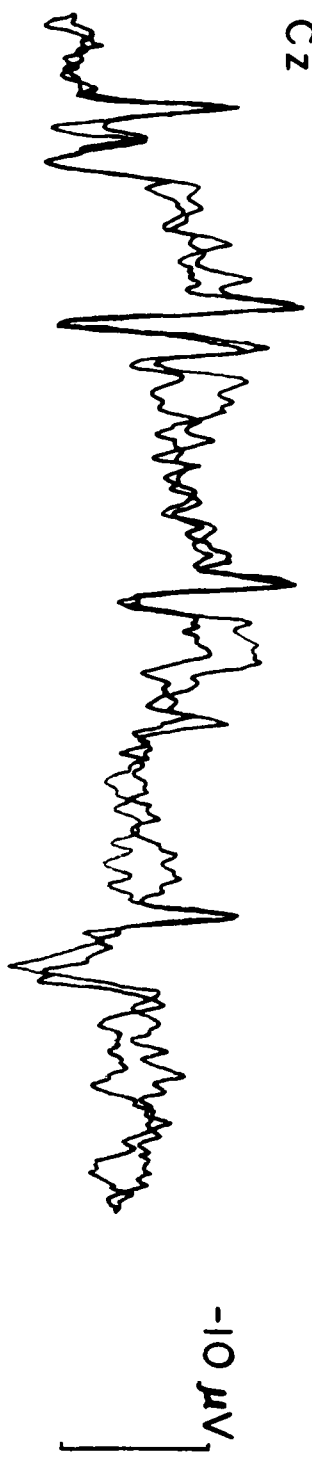
S off = Slide off

FB = Feedback toneburst

1000 HZ = Correct response

4000 HZ = Incorrect response

CZ



brief click (warning stimulus--WS) served to warn the subject that a slide was soon to be presented. After a delay of approximately 800 ms the slide came on (S on) and remained on for 1.2 seconds. There was a one second response contingency time after slide offset (S off). The subject's response was made within this contingency time, a response outside of this period having no relevance and causing no feedback to be given. If a response was made within the allotted time, the subject received auditory feedback (FB) approximately 1.5 seconds after S off. A 4,000 Hz toneburst signified an error, while a 1,000 Hz toneburst indicated a correct response. Trials were experimenter initiated every 8-15 seconds.

#### Experimental and Control Tasks

One experimental condition and two control conditions were designed, each using the basic paradigm described in the previous paragraphs. Upon the presentation of a slide in the Experimental condition, the subject made an hypothesis as to what the criterion was and pressed the button according to this criterion. Using the feedback he obtained during this attempt, he tried different solutions until he achieved the correct answer. The same criterion continued until the series was completed. The criterion then changed without specific warning and the subject again began his trial and error approach to learning the new correct criterion.

An example should clarify the procedure. If the correct criterion for a series of slides was the concept colour, the slides in that series

were coded such that only the button corresponding to the colour of the shape(s) on the slide would allow correct feedback to be given. For a slide with one red square with the written number two, button number one would be correct (refer to Table 2). If the subject hypothesized shape, and therefore pressed button two for square, he received disconfirming feedback. He had, however, eliminated two possible responses (if he thought quickly enough): shape, and mathematical operations ( $2 - 1 = 1$  requiring button 2 response). If the next slide was two blue crosses with the number two in the centre, button two would be the correct response for the concept colour, as it represents blue. However, if the subject did indeed press button two on this occasion and obtained correct feedback, he had not ruled out the possibility of the criterion being the number of forms. The subject may therefore not always be absolutely sure that he has chosen the correct criterion until more than one correct feedback has been obtained.

Two control conditions were designed to evaluate the roles of non-learning attention to the task as well as the actual conceptual learning.

The Distraction control condition was designed to occupy the subject's mind with a sufficiently difficult task so that he was unable to attend to the stimuli at all. The task was a serial subtraction task of some difficulty, described in Appendix 2. The subject saw the slide and heard all the auditory stimuli but was not required to respond at all.

His only task was to keep his mind occupied with the serial subtraction while keeping his eyes fixated on the slide screen. Feedback during the Distraction control was manipulated by the experimenter and given in such a manner that it would closely approximate the experimental conditions. The first one to three slides were given accompanied by the high toneburst feedback and the next 8-10 slides were accompanied by the low toneburst feedback. Usual variations obtained in the experimental conditions were also used, such as an occasional correct feedback toneburst in the midst of the run of incorrect.

A second control condition, known as the Known Concept control, was similar to the experimental task in the subject's responsiveness but this time, however, the subject was informed of each new criterion prior to the criterion change. Theoretically, then, although information processing was necessary, there was no learning involved in this task and the feedback was meaningless. Feedback was given in the same general manner as in the Experimental condition but was randomly located within each series to prevent as much as possible any signal value of the feedback stimulus. Three consecutive incorrect feedbacks were given within each concept. The subject was informed that this changing of the feedback would occur, but that his response was still correct and that he should therefore ignore the feedback stimulus.

The Distraction control was designed to demonstrate baseline stimulus-related conditions in the experiment, and the Known Concept control was used to show the effects of routine attentional and intentional

engagement in the task without the occurrence of any conceptual learning. The general concept of the control and experimental conditions is given in Table 3.

The experiment was performed along a repeated measures design, each subject being tested in all conditions. This type of design was chosen because of the fairly large inter-subject variability in reported evoked potential measurements: for example, the amplitude of the auditory evoked potential between subjects has a standard deviation of approximately one-third the actual measurement (Beagley and Knight, 1967). The repeated measures design alleviates this source of variability. However, it provides multiple other problems. The possibility of time-dependent differences between conditions was controlled for by the randomization procedure. However, the possibility of "carry-over" effects (Edwards, 1972, p. 322), e.g., the subject paying attention to the feedback stimulus in one condition in the same way as he has learned to do in another, poses a real problem. As such, it is nevertheless a problem that tends to decrease the probability of a type one statistical error, and therefore makes more confident any statistical rejection of the null hypothesis.

### Subjects

Twelve right-handed males were tested as subjects in both the experimental and control conditions. The subjects were acquaintances of the author who had volunteered their services. The data from one of the subjects are eliminated because of confusion in the feedback

Table 3

Relationship of the Three Conditions  
(Experimental, Known Concept, and Distraction)  
to Psychological Processes

Psychological Processes	Condition		
	Distraction	Known Concept	Experimental
Stimulus Sensation	+	+	+
Attentional-Intentional Engagement	-	+	+
Conceptual Learning	-	-	+

stimuli. Five of the subjects had been tested on a similar pilot study three months earlier. One of these was the individual whose data were rejected. Of the eleven subjects whose data were analyzed, then, four had been previously tested. Three of the subjects were well acquainted with the design and purpose of the study, and the rest were more generally informed according to the instructions in Appendices 1 and 2. The subjects were paid five to ten dollars based upon the duration of their participation (1 day or more). The subjects were aged 23 to 33 with a mean of 28.8 years. All subjects were administered the Minnesota Multiphasic Personality Inventory as a general control for mental pathology, since some authors have reported changes in evoked potentials correlated with psychological and psychiatric diagnoses (Shagass, 1971; Timsit-Berthier et al., 1973). No subject had any measure over the 70th percentile on this test except on the MF scale.

#### General Experimental Protocol

The subject first read the instructions and then was trained to do the task. The first step in this training consisted of showing the subject some slides in order to acquaint him with their general appearance and content. The subject was then required to familiarize himself with the responses for the buttons. Using one of the carousels, a series of practice trials was given. Leaving the slide on for an extended period of time, the subject practised responding to known criteria. After

attaining some proficiency in his response, the problem of criterion change was introduced. During all this training the slide on time was being reduced to the stipulated experimental period.

The second major step in the training was the learning of how to minimize evoked potential artifacts due to extraneous movements, eye-blinks and eye movements (Hillyard & Galambos, 1970; Picton & Hink, 1974). Eye movements were monitored during the practice session and feedback was given to the subject until he mastered the art of thinking and responding without blinking or moving for the duration of the evoked potential sweep. The subjects developed two basic patterns. One was not to blink for an extended time, a method used only occasionally by a few subjects. Most subjects learned to blink in a period of time after a feedback was given and then fixating to wait for the next warning stimulus. The experimenter, monitoring the eyeblinks, was generally able to tell when the blinks were over and the eyes fixated, and then initiated the next sweep. The subjects were also instructed to inform the experimenter if the button was pressed erroneously or if something was wrong.

Between the practice and testing sessions, this period of time varying from days to weeks, the subjects were instructed to memorize and practise the use of the response buttons so that the actual motor response became quite automatic.

The subjects arrived generally about 8:30 a.m. on the day of testing, although two subjects were tested in the afternoon. Electrode application took approximately an hour. During this time subjects were

allowed to smoke or have a cup of coffee if they so desired. The experimenter also reviewed the button response contingencies and the subject's knowledge of the test.

The subject sat in the testing room with a pillow behind his neck if he wished. There was a five to ten minutes adaptation time during which period the experimenter was able to recheck the recording and stimulation equipment. The testing took approximately 30-40 minutes for each carousel with four carousels being presented. After the second carousel, a break of 15-20 minutes was given during which time the subject could stretch, smoke or have a cup of coffee if he wished.

Four carousels of slides were presented to each subject. Two of these carousels were for the experimental condition and one was for each of the control conditions. Presentation of carousels was randomized in the following manner. First, all 24 possible arrangements of the carousels were established. The two experimental carousels were arbitrarily blocked as one, leaving six possible combinations of experimental and control conditions. These were superimposed four times on the carousel randomization. These possibilities were then randomly distributed to the subjects (see Table 4).

When the electrodes were being removed, after completion of testing, the subjects were required to fill out a questionnaire (Appendix 3). The purpose of this post-experimental questionnaire was to tap subjective experiences during testing which may help explain physiological evoked potential changes.

Table 4  
Randomization of Carousel and  
Condition Presentation

Total Random Combinations	Carousel-Condition				
1	2	1	4†	3*	
2	4	3	2*	1†	
3	1†	2	3	4*	
4	3†	2*	1	4	
5	4*	1	2	3†	
6	2*	3†	1	4	
7	2†	1	3	4*	
8	4*	2	3	1†	
9	3†	1*	2	4	
10	2	4	3†	1*	
11	1*	4†	3	2	
12	3	4	1*	2†	
13	1*	3†	4	2	
14	1	3	2*	4†	
15	4†	2	1	3*	
16	4	3	1†	2*	
17	2*	4	1	3†	
18	2†	3*	4	1	
19	3*	4†	2	1	
20	3*	2	4	1†	
21	4†	1*	3	2	
22	1†	4	2	3*	
23	3	1	4*	2†	
24	1	3	4†	2*	

Legend

1. 1, 2, 3, 4 = Carousels I, II, III, IV
2. † = Distraction Control
3. \* = Known Concept Control
4. Not Delivered = Experimental Condition

The MMPI was given at the availability of the subject which may have been either before or after the testing session.

### Recording Techniques

Eleven Beckman standard 16 mm diameter silver-silver chloride electrodes were used for all except the eye electrodes, where the 11 mm Beckman electrodes were used. These electrodes were filled with isotonic saline electrode jelly and attached with the appropriate adhesive collars either to gauze pads glued with collodion to the scalp or directly to the skin. Each day after being used the electrodes were cleansed and soaked in normal saline, the leads plugged into copper shielding. Skin surface areas were prepared for electrode placement by cleansing the skin with cotton soaked in acetone, and by then scratching the skin with a sterilized hypodermic needle to prevent skin potential artifacts (Picton & Hillyard, 1972). Electrodes were placed at the following scalp positions: F3, F4, P3, P4, CZ, OZ (Jasper, 1958). A linked mastoid reference was used with each mastoid electrode being in series with a 10 KOhm resistor. The electro-oculogram was recorded between supra- and infraorbital electrodes. A ground electrode was placed on the left arm. Inter-electrode impedance was measured at 10 Hz. The inter-electrode impedance for scalp and mastoid electrodes was always less than 1 KOhm and for the other electrodes was less than 2.5 KOhms.

EEG and EOG activities were amplified, recorded and monitored on a Nihon-Kohden 8-channel multipurpose polygraph model RM-85 with an

8-channel oscilloscope monitor model VC-85. The six EEG channels were amplified on biophysical amplifiers model RB-5 modified to have a time constant of 6.8 seconds. The high-frequency cut-off on these channels was 30 Hz. EOG activity was amplified on a model RDU-5 DC amplifier with a bandpass of DC to 300 Hz. The outputs of all of these seven channels were recorded on a Vetter 700 series model A 8-channel FM taperecorder at a recording speed of 3 3/4 inches per second. The synchronization pulse and the feedback stimulus monitor were recorded on the final tape channel and on one of the polygraph channels. 3M Scotch brand magnetic tapes Pro-pack 206 1.5 ml high-output low-noise recording tapes were used. Selected taperecorder channels were monitored during recording by oscilloscope in order to prevent any taperecording artifacts. On-line counting of the trials was performed using a Lafayette counter model 5804. Two channels of taperecorded data were averaged on-line using a Nihon Kohden averaging data processor model Atac-201, in order to check on the general quality of the evoked potentials.

#### Stimulus Presentation

The subject sat in a comfortable easy chair in a separate sound-attenuated room facing toward a white paper screen pinned to the opposite wall five feet in front of the subject's eyes. A visual fixation point was marked in the center of the screen. The size of the projected image on the screen was 43 inches wide by 29 inches high, i.e.

subtending visual angles of  $39 \times 27^\circ$ . Behind and above the subject situated in the adjoining room behind a window was a Kodak carousel 800 projector modified by a Lehigh Valley Electronics solinoid-driven shutter in connection with a model SCP-602 slide coding panel. This modified projector was able to "read" the slides that had all been previously coded by means of appropriate holes in the slide mount in order to determine the necessary response to that slide. All slides were coded for responses according to the sequencing as determined in Table 1.

On the arms of the chair on which the subject was sitting was placed a flat wooden surface on which was a rectangular metal box with the four response buttons arranged on it to fit comfortably to the outstretched fingers of the right hand. This box was connected to the slide coding panel such that the correct button response would correspond to the correct code read by the projector. Two Lafayette Instrument auxiliary latching relays model 5813 were triggered by the coded slide and acted as memories to indicate whether the button pressed was correct or incorrect. These allowed gating of one of two Hewlett Packard oscillators model 2043 which generated the correct or incorrect feedback tones. Feedback was monitored on the polygraph and taperecorded by a downward negative deflection, with incorrect being half the amplitude of the correct.

The timing of the entire operation was effected by a Lafayette 8-bank timer model 543-A. The warning stimulus was obtained from a

Lafayette triple pulse former, model 5821. The warning stimulus and the feedback tones were heard by the subject through Symphonic headphones model DH288 over a background of white noise generated by the Lafayette white noise generator model 15011.

Schematics for the stimulus presentation logic are presented in Figure 3.

### Data Analysis

Prior to averaging, each series was divided into five divisions. Each division was designed to follow the probable changes in the trial and error learning process. Each division was defined by the ordering of the feedback stimuli, and were labelled the five stages of stimulus sequences. Thus the divisions were also applicable to the control conditions wherein there was no actual learning occurring. Since the possible effects of learning were most relevant, the stages of stimulus sequences were termed as if they always referred to a possible learning sequence. They are operationally defined, however, as referring to the ordering of feedback stimuli. The divisions were

1. Preinsight (PINS)--these trials were those with incorrect responses following the change of concept (False Feedback) and preceding the attainment of the correct concept (Insight).

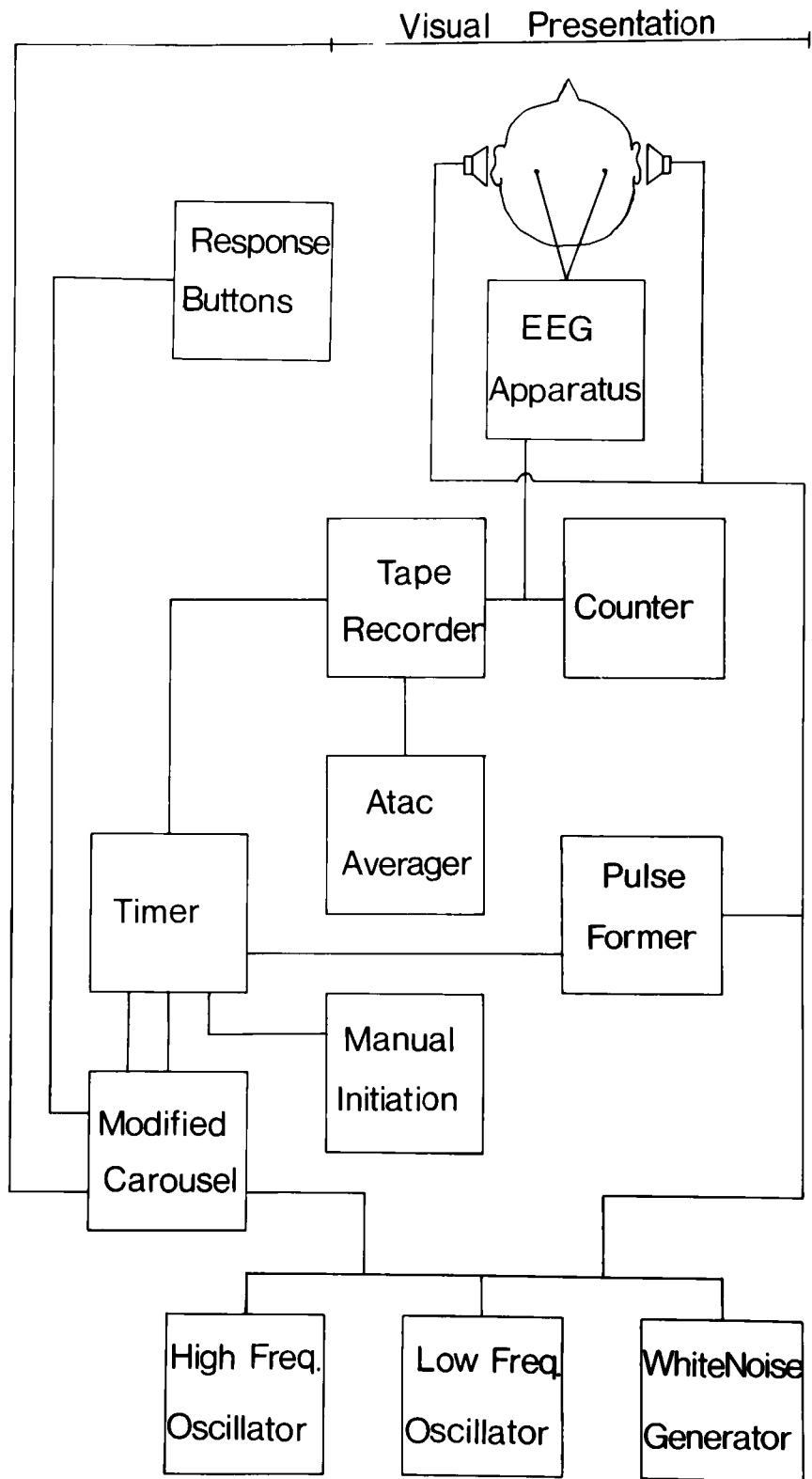
2. Insight (INS)--the first two correct responses in a run of at least four consecutive correct responses after Preinsight. Two were included in this division since the first correct feedback did not necessarily tell the subject that he had chosen the correct criterion.



Figure 3

Equipment Schematics

This figure illustrates in a schematic overview the technical operation of the experimental apparatus.



3. Confirmation (CON)--the two consecutive correct responses following Insight.

4. Overlearning (OVER)--all correct responses between confirmation and the change of concept (False Feedback).

5. False Feedback (FFB)--the trial which changes the former criterion to a new one. It is the trial in which the subject made presumably the correct response but obtained an incorrect feedback stimulus.

Distraction control, mimicking closely the experimental feedback, is easily defined. That is, those trials with high tones preceding four consecutive low tones will be called Distraction Preinsight, etc.

Known Concept control is defined as follows:

1. False Feedback (FFB)--the first of three consecutive high tone responses no matter where it falls in the series.

2. Preinsight (PINS)--the next two of the three consecutive high tone responses.

3. Insight (INS)--the first two low tone feedback responses no matter where they occur in the series, i.e., they may fall on either side of the three consecutive high tone response.

4. Confirmation (CON)--the next two low tone feedback responses.

5. Overlearning (OVER)--the remaining low tone feedback responses.

Trials in which the response was not given in time, or in which eye movement, skin potential or muscle artifacts may have confounded the

evoked potentials, were eliminated after surveying the polygraph writeout. Other possible measurements, such as misses or mechanical errors in a run of correct responses, or correct responses in a series of Preinsight with incorrect responses, were not analyzed.

The tapes were played back on a second Vetter FM taperecorder at a speed of 15 inches per second, i.e., at four times the recording speed. The channel with the synchronization pulse was connected to the trigger input of a Tracor Northern NS-575A digital signal analyzer with an 8-channel input module NS-594-8. The trigger channel also was connected to a Tektronix DC 504 counter which served as a means of identifying the sweeps which were to be averaged according to the different stages of stimulus sequence as described in the previous paragraphs. One stage of stimulus sequence was averaged at a time by manually selecting the appropriate trials from a number of series within a condition. The final average for a specific stimulus sequence within a specific condition consisted of 12 (or multiple of 12) trials of that stage selected from different series within that condition.

EEG and EOG output from the taperecorder channels were conditioned by using Tektronix AM502 differential amplifiers with unit gain and frequency bandpass of 0-100 Hz. This enabled all outputs to be positively offset from 0 in order to match the requirements of the input module of the signal averager. Eight channel averaging (the 7 electrophysiological channels and the synchronization and stimulus monitor) was

performed for each selection of trials over a period of 1.28 seconds. Due to the ratio of record to playback speeds this was equivalent to 5.12 seconds in real time.

The average data for each division was plotted on a Hewlett-Packard XY recorder model 7044A.

### Calibration Techniques

#### Sound levels

Sound pressure levels were calibrated using a Brüel and Kjaer impulse precision sound level meter type 2204 with a type 4152 artificial ear coupler. The ambient room noise was between 60 and 70 decibels SPL. The quick warning stimulus was 95 decibels impulse peak SPL and both feedback tonebursts were 88 decibels SPL. The background white noise in the earphones was 65 decibels SPL.

#### Visual stimuli

Light levels were measured using a Spectra Pritchard photometer model 1970-PR. The photometer was placed in the same position as the subject. The ambient light in the room with the slide off was 35 millilamberts. The slide intensity varied with the portion of the slide examined from 260 millilamberts in the slide background to 2.1 lamberts in the white letters.

#### Stimulus timing

The timing for the stimulus presentation was measured using a universal counter Racal 835 which was accurate to within 10  $\mu$ s over a 5 second sweep. The auditory stimuli were monitored for timing by the

Brüel and Kjaer sound level meter and the slide onset and duration was monitored by a Darlington photocell. The actual time between beginning of the synchronization pulse and the onset of the click was found to be 310 ms. The onset of the feedback toneburst occurred 3810 ms from the synchronization pulse. The duration of the feedback stimulus was 100 ms. The slide onset began at 1175 ms after the synchronization pulse and the duration of the slide was 1,200 ms.

Another calibration check was between taperecording and tape playback. Stimulus monitors were fed directly into the taperecorder using the regular settings and this was played back in the same manner as for data analysis. There was no distortion involved in taperecording and playback. The accuracy of any latency measured due to both calibration errors and actual measurement errors can be considered to be within ten ms.

#### Amplitude calibration

Amplitudes of the evoked potentials were calibrated by recording a single trial of a 100 microvolt pulse through the polygraph, taperecorder, amplifiers, and signal analyzer. Prior to averaging, the individual channels of the taperecorder were adjusted to be within 5% of each other. Due to variations in the calibration and the measurement techniques, any amplitude measurement is considered accurate to within 10%. There were no systemic errors in amplitude estimation between electrodes or between conditions.

### Frequency bandpass

The overall frequency bandpass of the amplification taperecording and signal analysis was measured by feeding constant voltage sine waves at different frequencies into the polygraph input, amplifying this signal on the polygraph amplifiers, taperecording it, and playing it back into the signal analyzer using the exact same settings as for data analysis. Ninety percent frequency bandpass limits of the whole system was 0.1 to 8 Hz (see Figure 4).

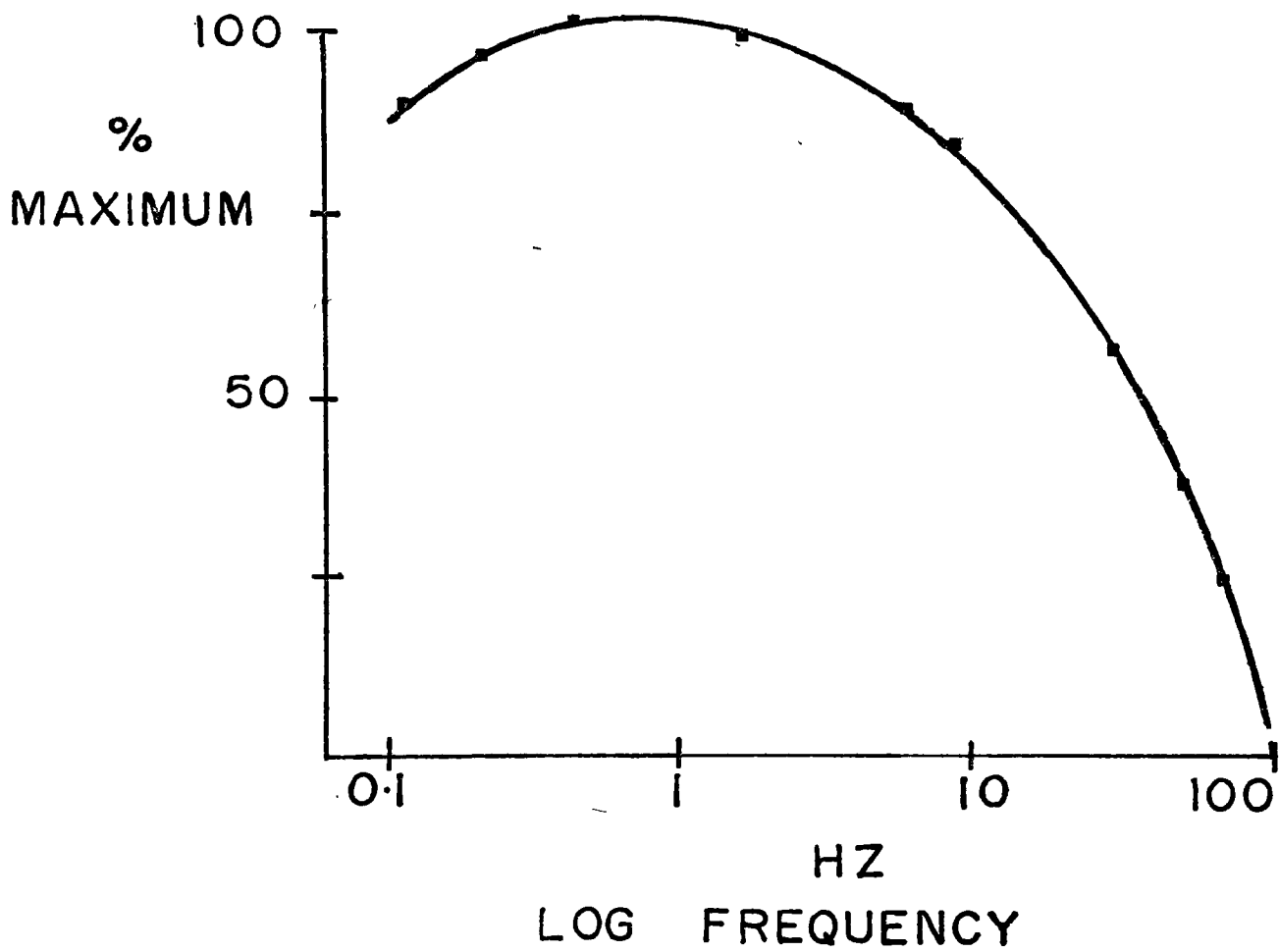
### Dependent Measurements

Multiple measurements can be made on the obtained data. Based upon the preliminary pilot studies, it was decided to limit the full statistical analysis to only ten variables. This limitation served both to simplify the computational procedures and to increase the power of the statistical analysis.

Baseline-to-peak measurements of the average wave forms were used in preference to peak-to-peak measures because such measurements are physiologically more relevant (Goff et al., 1969, p. 105). The drawing of a baseline poses its own particular problems. With the prolonged time constant recording methods, long-lasting slow potential shifts effecting the underlying baseline could have been recorded. Such shifts may have been related to changes in cerebral electrical activity, either related to or independent of the experimental procedure. Electrode, amplifier and skin potential baseline shifts are another cause of such

Figure 4System Frequency Transfer Functions  
(from Electrode Box to XY Recorder)

The overall frequency bandpass was measured by comparing the amplification response at different frequencies to a constant voltage sine wave. The amplification response of different frequencies were compared by relating each as a percentage of the maximum. Frequency range is presented on a logarithmic scale.



slow changes. There are, therefore, two means of drawing the baseline. One involves the arbitrary construction of a line through the initial waveform prior to the first stimulus and parallel to the time axis. The other technique involves drawing a line between the average EEG signal before and after the stimulus sequence. This latter technique decreases the variance of the baseline dependent measures that might be caused by underlying very slow potential shifts. The actual baseline shift during the period of examination could also then be used as a dependent measurement and its changes with the experimental manipulation and its correlation with the other variables analyzed for significance. Therefore the baseline was drawn between the mean value of the waveform in the 300 ms prior to the click and the mean waveform level in the final 200 ms of the analysis. Examples are illustrated in Figure 5.

Having drawn the baseline, the following measurements were taken as illustrated in Figure 6:

1. Slide CNV--the average level of the waveform above the baseline in the 400 ms preceding the onset of the slide.
2. Slide P<sub>3</sub> amplitude--the peak amplitude from baseline of the maximum positive deflection between 275 and 500 ms after the slide onset.
3. Slide P<sub>4</sub> amplitude--the peak amplitude from baseline of the maximum positive deflection between 500 and 800 ms after the slide onset.
4. Slide slow potential--the average level of the waveform above baseline in the last 600 ms of the slide illumination.



Figure 5

## Baseline Construction

Examples of baseline construction for CZ electrode sites indicate the range from the worst negative offset (bottom: Subject N.H., Experimental False Feedback) to the worst positive offset (top: Subject N.H., Known Concept Overlearn). The middle sweep (Subject T.P., Experimental Preinsight) is a typical representation of the average offset.

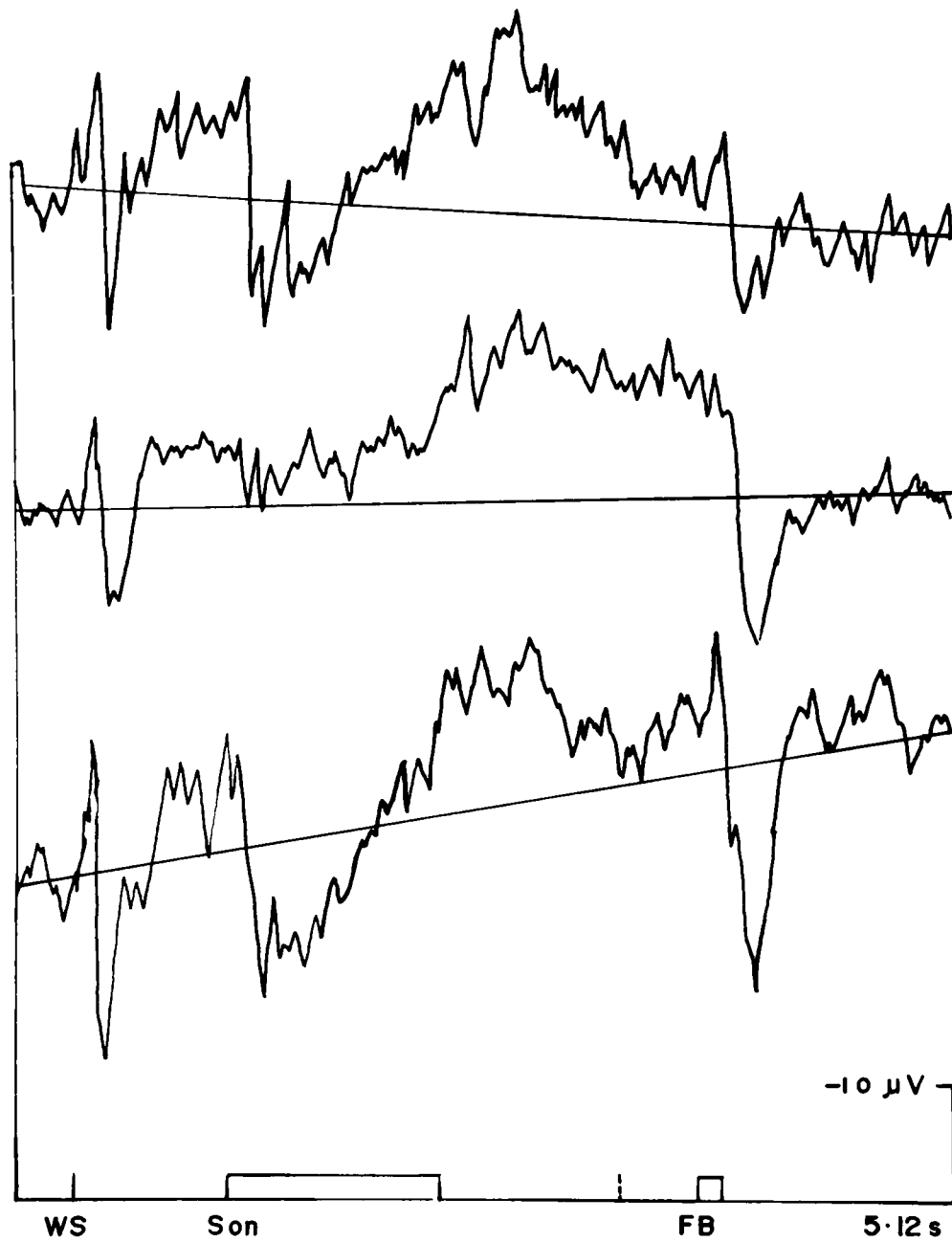
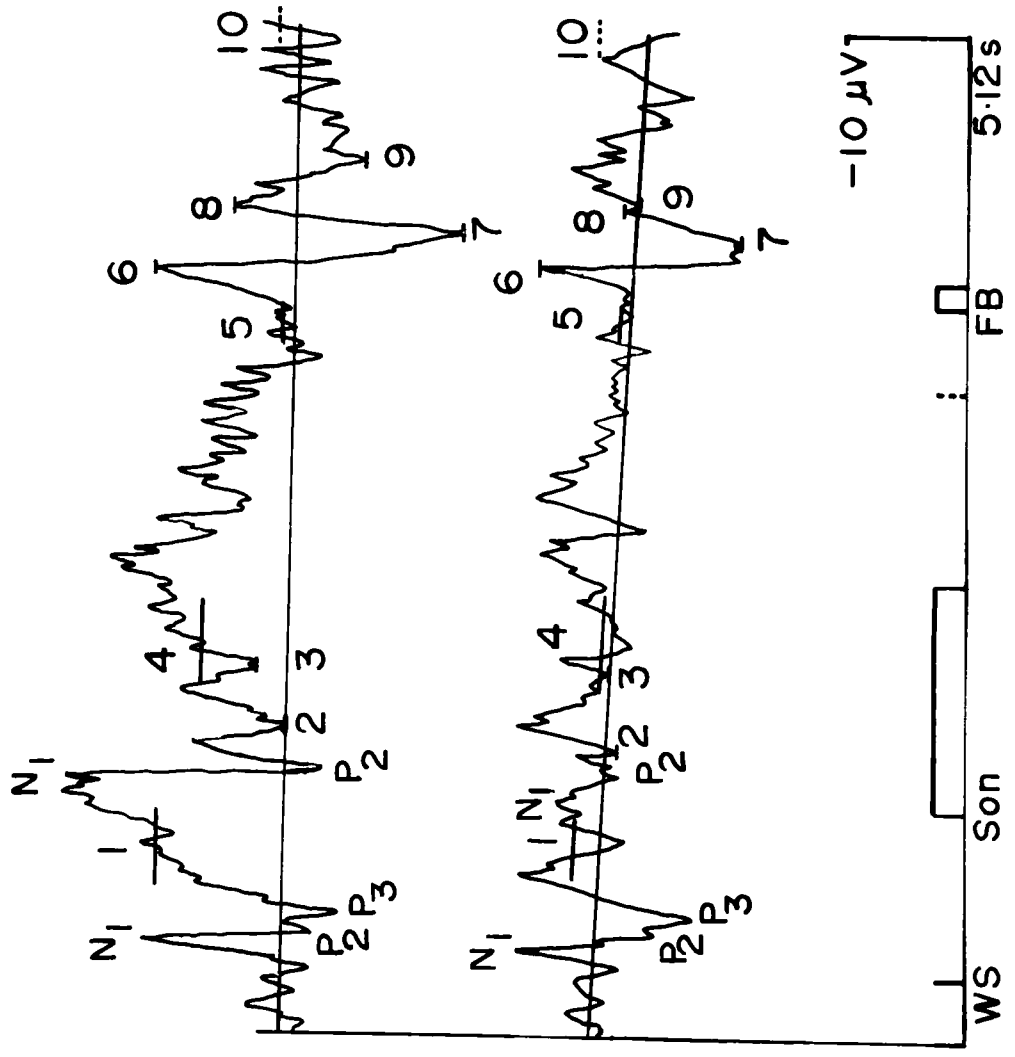


Figure 6

## Dependent Measurements

Statistical analyses were based upon the baseline to peak measurements numbered 1 to 10. Other labelled peaks were not analyzed, but are schematically represented in Figures 8 to 12 to indicate their relative stability. Top example: Subject G.N., CZ Experimental Overlearn. Bottom example: Subject T.P., CZ Distraction Confirm.



5. Pre-feedback CNV--the average level of the waveform above baseline in the 200 ms preceding the feedback tone onset.

6. Feedback  $N_1$  amplitude--the amplitude from baseline to the maximum negative peak between 80 and 150 ms after the feedback tone onset.

7. Feedback  $P_3$  amplitude--the baseline to maximum positive peak measurement between 275 and 500 ms after feedback onset.

8. Feedback  $N_3$  amplitude--the amplitude of the baseline to maximum negative peak between 350 and 550 ms after feedback onset.

9. Feedback  $P_4$  amplitude--the amplitude of the baseline to maximum positive peak between 500 and 800 ms after feedback onset.

10. Baseline offset--the difference between the average level in the final 200 ms of the waveform and the average level in the initial 300 ms prior to the click stimulus.

Several other measurements were taken and tabulated without being fully analyzed. For example, the response to the warning click stimulus was not considered to be highly relevant to the learning process and therefore the  $N_1$ ,  $P_2$  and  $P_3$  amplitudes in this response were not analyzed. The slide onset evoked potential was very difficult to interpret since the morphology of the response is quite variable between electrode locations. Because of the decreased latency resolution involved in the five second sweep analysis, it was impossible to determine whether these morphological differences definitely represented separately generated components at the occiput and in the anterior head regions,

as postulated by Lehtonen (1973), or the phase reversal of a focal occipital dipole. Because of these difficulties in interpretation, analysis was not performed on the measures of the slide onset response between 70 and 275 ms. However, a peak to peak measurement was measured and tabulated at the vertex to demonstrate the relative constancy of this response. The one second "response period" occurring after the slide offset was not examined because the response was made at a random period of time during this period and therefore no time locked potentials preceding the response could be accurately measured. There was also the possibility of some movement artifact during this period of time. Feedback P<sub>2</sub> was not measured due to difficulty in determining its peak because of the closely following P<sub>3</sub>. Additional measurements were tabulated (such as N<sub>1</sub> - P<sub>3</sub> peak to peak) and analyzed if it was considered necessary to explain problematic results.

The latencies were measured in the Experimental condition for the components whose peak amplitudes were evaluated. Because most of the peaks were defined on arbitrary latencies, possible differences or lack of differences in latencies are difficult to evaluate and therefore the latencies were merely tabulated rather than being fully analyzed.

### Statistical Analysis

The analysis of data obtained in this experiment required the evaluation of the effects of three separate conditions, each with five

stages of stimulus sequences upon the ten evoked potential measurements recorded at six scalp electrode locations in eleven subjects, with each subject being evaluated under all conditions, all sequences, and all scalp electrode locations.

Theoretically, the most correct statistical analysis procedure would involve a multivariate analysis. However, the programming for such a three-factor multivariate analysis of variance with repeated measures on all three factors is exceedingly complex both in computation and interpretation, and is not readily available. A second alternative would be to use a three-way univariate analysis of variance with repeated measures on all factors for each of the attendant measurements with some necessary changes in the significance level to compensate for the fact that multiple tests were performed. The interaction effects in such an analysis are, however, exceedingly complex and confusing. The effects of scalp electrode location upon the evoked potential components was also of theoretical interest only to the Experimental condition in order to determine whether the sequence of learning stages change the evoked potential component scalp distribution to any significant degree. Therefore, it was decided to use the following two analyses:

1. A two factor analysis of variance with repeated measures for each subject on both factors, both factors being fixed and crossed. The two factors are (a) the "condition": (A1, the Experimental condition; A2, the Known Concept control condition; A3, the Distraction control condition); and (b) the "sequence" staging factor: (B1, the preinsight trials; B2, the insight trials; B3, the confirmed trials; B4, the overlearn trials; B5, the false feedback trials).

2. A two factor repeated measures analysis of variance for data in the Experimental condition alone with the two factors being (b) the "sequence" staging as in the first analysis; and (c) the "electrode location": (C1, the vertex; C2, the occiput; C3, the left frontal; C4, the right frontal; C5, the left parietal; C6, the right parietal).

The post-hoc testing of the differences between means for significant main effects after the initial analyses of variance were performed in both cases using a Tukey's honestly significant difference statistic.

To test the simple main effects if significant interaction was noted, the numerator, sums of squares, degrees of freedom and mean squares for each level of one factor at another were derived following conventional techniques. A pooled mean square error for each denominator was calculated following Winer (1971, p. 544-545). For the significance of  $F$ , it was decided to use an approximate estimation achieved by employing the appropriate degrees of freedom from the standard Anova table.

While this application was somewhat liberal, a more rigorous and precise test for the differences between simple effects based on a critical  $t$  value suggested by Cochran and Cox (1957, p. 299) and reported in Winer (1971, p. 544-545) was calculated. Thus, actual significance of the  $F$  ratio was determined by the absence or presence of a significant  $t$ . With this procedure, some approximate  $F$  tests were rejected.

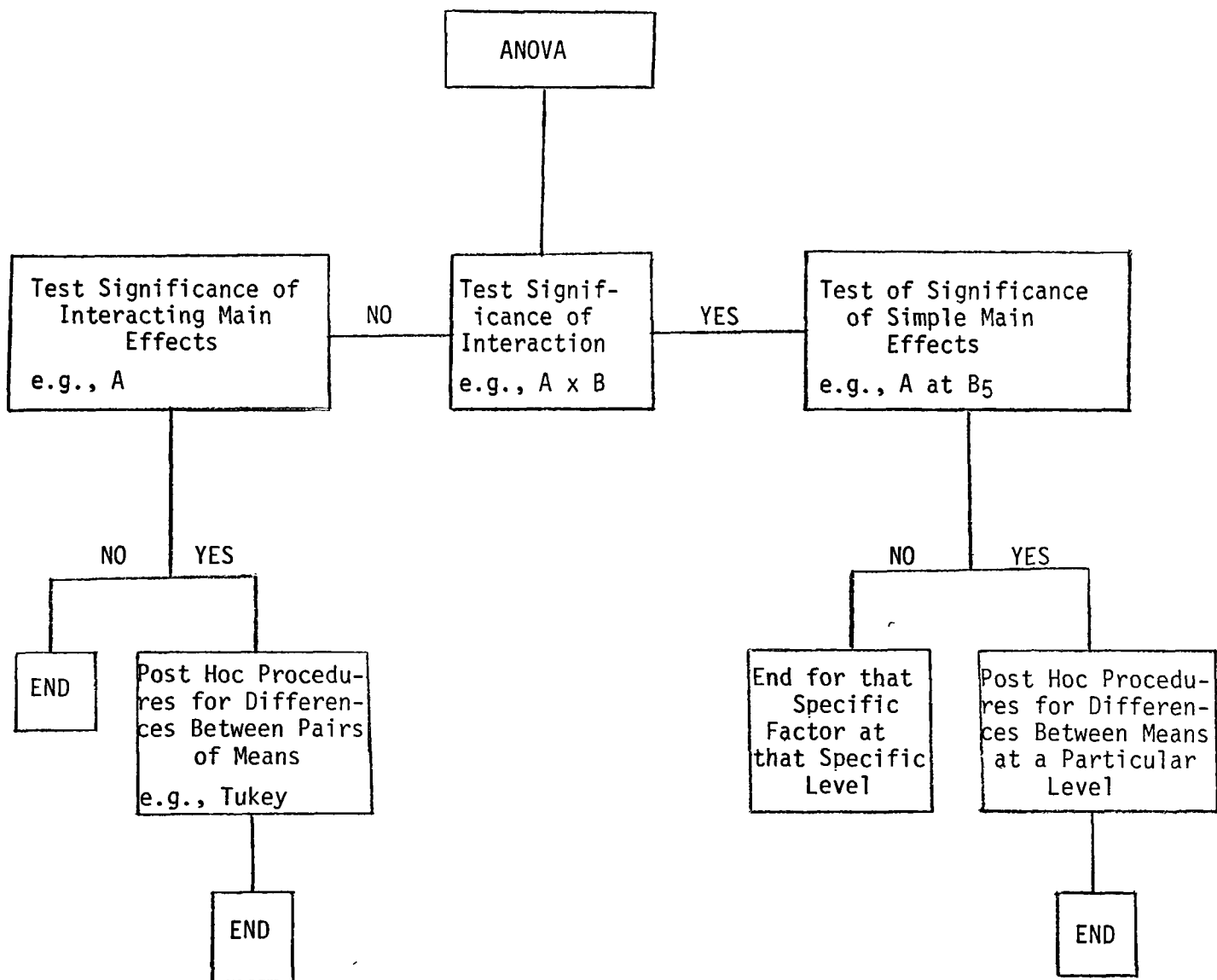
A schematic flow chart of the statistical procedure is presented in Figure 7.

Figure 7

Flow Chart of Statistical Procedure

The procedure for examining the evoked potential results for each dependent variable followed the logistics presented in the flow chart.

RELATIONSHIP BETWEEN SIMPLE EFFECTS  
AND THE STANDARD ANALYSIS OF VARIANCE



There are three basic problems involved in the data and its analysis. The first problem is that involved in multiple tests. The use of separate analyses for ten different variables increases the probability of a type I error if the same significance level is used as a criterion as when the analysis is used for only one variable. The choice of significance levels is a difficult decision. On one hand, one can choose to base the error rate upon each hypothesis tested, i.e. to use the usual .05 significance level. On the other hand, one may alter the significance level to decrease the error rate for the whole experiment, such as by decreasing the significance level by a factor equal to the number of hypotheses tested (Kirk, 1968, pp. 82-86). The latter procedure is perhaps overly conservative especially in view of the exploratory nature of this experiment. Therefore, a compromise on the significance level was made and it was chosen to use a 0.01 criterion for the analyses of variance. The post-hoc testing based upon the Tukey procedure is quite conservative containing the necessary compensations for the total number of possible comparisons to be made. Therefore the significance level for the post-hoc testing was maintained at 0.05. Post-hoc testing was only performed after the initial analysis of variance had obtained significance at 0.01 level.

The second problem involves the use of repeated measures. With repeated measures, subject interaction may very well result in problems of the assumptions of homogeneity underlying the analysis of variance (Keppel, 1973, p. 463). Repeated measures also increase the problems with

the added assumption of symmetry and equality of the variance-covariance matrix; i.e., it assumes the population covariances between pairs of treatment levels are constant (Kirk, 1968, p. 139). This assumption is also called the assumption of equal correlations (Edwards, 1967, p. 317).

The validity of this assumption may be tested using a Box's "M" statistic. The computational programmes of such a statistic are, however, complex and not readily available. It has, nevertheless, been shown (Edwards, 1967, pp. 317-319) that the lack of equality of variances and correlations effect the  $F$  ratio similarly to reducing the degrees of freedom by a specific fraction  $\theta$ . Since the absolute minimum value of this fraction is equal to  $1/(T-1)$  where  $T$  is the number of levels of a factor, Geisser and Greenhouse (1958) developed the conservative  $F$  test in which the degrees of freedom for  $F$  are multiplied by  $1/(T-1)$ . This conservative  $F$  test gives correct significance levels even in the presence of maximum heterogeneity of the measurements. It is an extremely conservative test and it is seldom used, although often recommended (Edwards, 1967; Johnson & Lubin, 1972; Keppel, 1973; Kirk, 1968; Knott & Peters, 1974).

The actual procedure consists of completing the analysis of variance in the usual manner and obtaining an analysis summary table. The degrees of freedom for both numerator and denominator are multiplied by theta and these are then entered into the  $F$  table to yield the

conservative  $\underline{F}$ . The use of such a testing procedure will markedly decrease the number of statistically significant rejections of the null hypotheses, especially those involving the interaction variances. If a test turns out to be significant using the conservative  $\underline{F}$ , one is certain of significance no matter how much the assumptions of the analysis of variance were violated.

If the testing is significant using the conventional  $\underline{F}$  test but not using the conservative  $\underline{F}$  test, there is uncertainty as to whether or not to reject the null hypothesis. In this case one may use the Hotelling's  $T^2$  statistic to determine the exact significance levels. The programming for such a statistic for a design with repeated measures on two factors is quite complex and not readily available. A second procedure might be used to compensate somewhat for the extreme conservatism of the conservative  $\underline{F}$  test. This is to utilize a conservative  $\underline{F}$  but to utilize it at a significance level of 0.10 rather than .05. This is the procedure utilized in this experimental analysis.  $\underline{F}$  ratios are considered significant if both the conventional test significance level exceeds 0.01 and the conservative  $\underline{F}$  significance level exceeds 0.10. The  $\underline{F}$  table given by McCall (1975, pp. 355-358) was used.

The third major problem in the statistical analysis of the results involves the interaction between the experimental variables. For example, if under one condition there is a large negative baseline offset during the analysis period, this might bias the measurements of the other

variables such that the positive waves become more positive and the negative waves less negative. Because of this possible problem, baseline offset effects will be considered and discussed if the analysis of variance is significant even at a lower level than that decided on for the other variables. Also a Pearson  $R$  correlation coefficient will be determined between the baseline offset and the other dependent variables.

In general the approach to the statistical analysis of the data will follow much the general philosophy of Keppel (1973) as evidenced in the following quotation:

The statistical procedures are guides to aid us in guessing at which facts are "real" and which are not. In the absence of any other information, rigid decision rules, where we maintain alpha at an arbitrary level, makes some sense. But if a finding is interesting theoretically, we should not ignore its presence merely because it fails to exceed the critical  $F$  value or its corrected value. Agreement with previous experiments and internal consistency with other response measures in the current experiment are important factors that we should take into consideration when we are drawing inferences from our data. The pure statistical arguments represent one input contributing to our final decision. (pp. 466-467).

### Hypotheses to be Tested

The first analysis of the data is directed to determining genuine learning-related electrophysiological events that are independent of mere attentional or intentional engagement in the perceptual task. The general approach of this analysis is based upon the theoretical considerations given in Table 3. The basic possibilities of the statistical analysis are a significant main effect of Conditions, a

significant main effect of Sequence and a significant interaction of the two. A significant condition effect may demonstrate an overall learning phenomenon if on post-hoc testing a significant difference is found between the Experimental and the Known Concept control conditions and a significant attentional/intentional effect if a significant difference is found between the Known Concept and the Distraction control conditions. A significant sequence main effect will indicate stimulus related changes independent of attention or learning. A significant interaction effect, or significant differences on both main factors, will indicate some definite electrophysiological phenomenon related to attention or learning or both. Post-hoc testing will then determine in which parts of the sequence the phenomenon occurs and whether with attention and/or with learning.

The specific null hypotheses for this analysis are the following:

1. There are no significant differences among the three experimental conditions for each of the dependent measurements.
2. There are no significant differences among the five sequence stages for each dependent measurement.
3. There are no significant interaction effects among the experimental conditions and the stimulus sequence for each dependent measurement.

The second analysis concerns itself with the effects of the various stages of the learning sequence (Experimental condition) upon the scalp distribution of the components that are measured. The null hypotheses to be tested in this analysis are these:

1. There are no significant differences among the electrode locations in the measurement of the dependent variables.
2. There are no significant effects of the stages of the learning sequence upon the dependent measurements.
3. There is no significant interaction between the stages of the learning sequence in the Experimental condition and the scalp distribution of the measured components as revealed by their electrode location measurements.

## CHAPTER III

### Results and Interpretation

Means and standard deviations for all raw scores upon which the ten statistically analyzed measurements are based are presented in Appendix 4. Appendix 5 reports the means and standard deviations of raw scores corresponding to evoked potentials not analyzed. A schematic representation of these means for each sequence stage, measured at the CZ electrode site within the Experimental condition, are represented in Figures 8 to 12. Figure 15 serves as an example of the results of a specific Experimental trial across the six cortical electrode sites.

Since, as was discussed in the methodology, Baseline Offset might influence multiple other measurements (Klorman, 1974; Tecce & Hamilton, 1973; Weerts & Lang, 1973), it will be considered first, (see Table 5A). Because of its possible importance, the level of conservative significance was set at .25. At this level, there was a significant interaction effect,  $F(8,80) = 2.14$ , conventional  $p < .05$ , conservative  $p < .25$ .

When the conditions were examined at each sequence stage (see Table 5B), significance was noted only with FFB, where both the Experimental and Known Concept conditions were significantly more negative in offset than the Distraction control, suggesting that this may be a post-imperative negative variation (Dongier, 1969; Picton & Low, 1971; Timsit, Koninckx, Dargent, Fontaine & Dongier, 1970; Weinberg, 1972, 1975). The

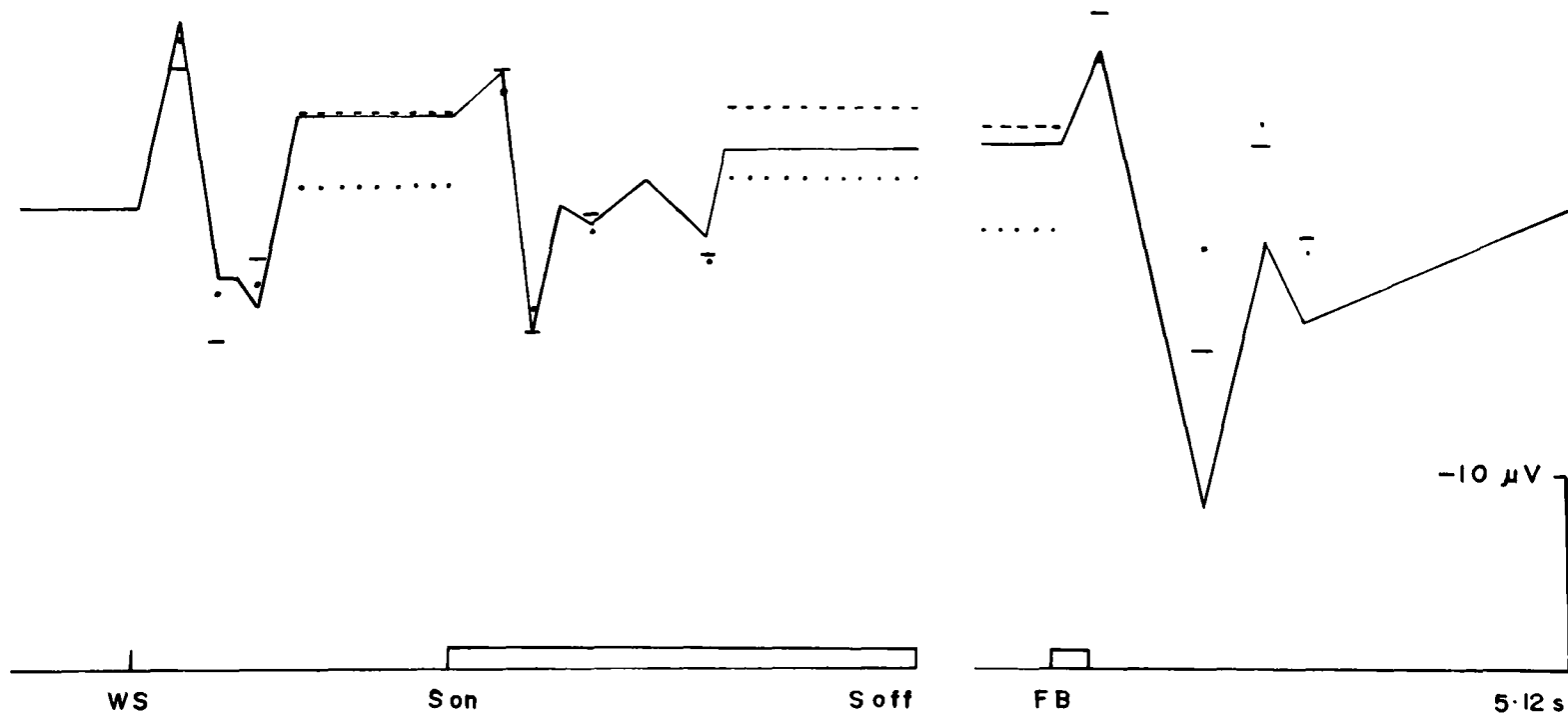
Figures 8 to 12

Schematic Representation of CZ Evoked Potential Results  
to a Concept Learning Task for Five Stages of Stimulus  
Sequence (Preinsight, Insight, Confirm, Overlearn and  
False Feedback) under Three Different Conditions  
(Experimental, Known Concept, Distraction)

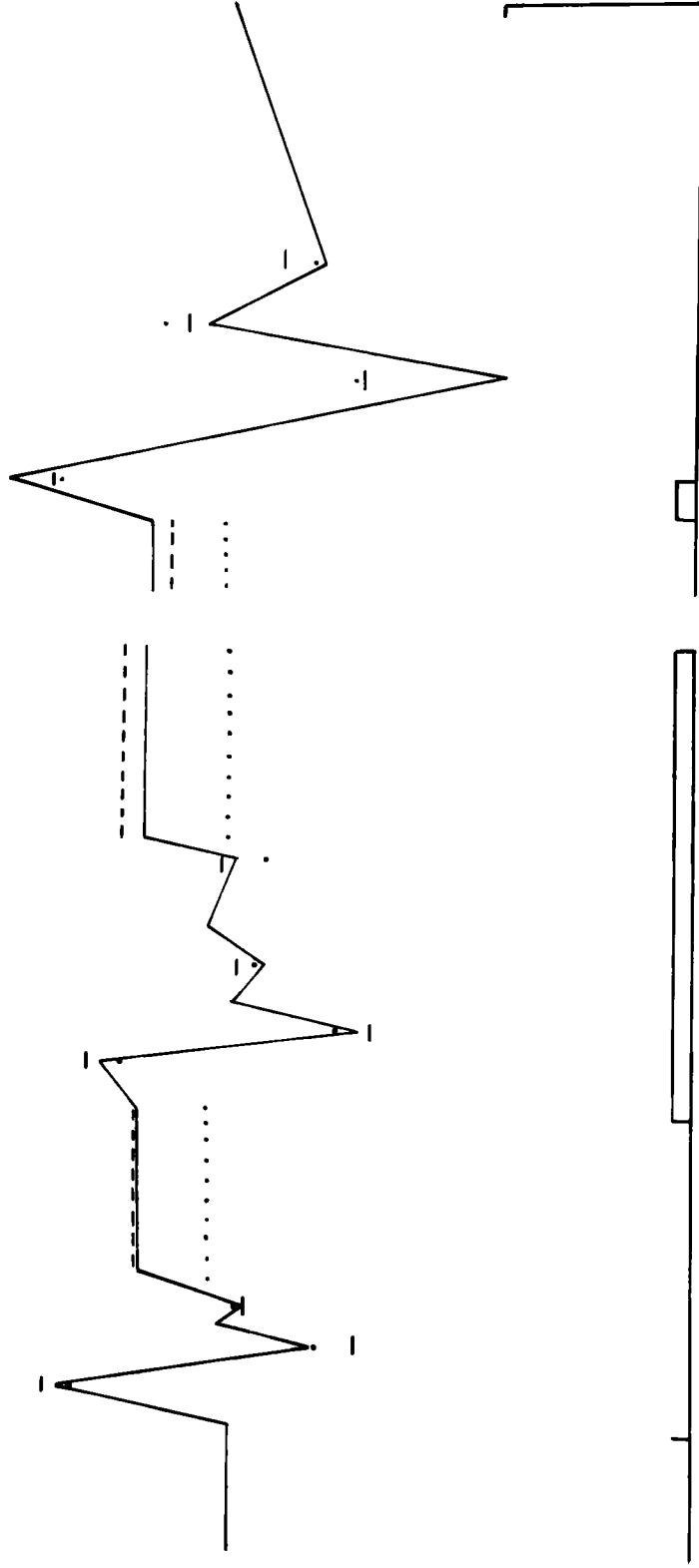
The means of eleven subjects for each variable designated in Figure 6 are presented in schematic form to facilitate visual comparison of results both through stage sequence (Preinsight, etc), and across conditions (Experimental, Known Concept and Distraction), all measured at the CZ electrode site. Baselines have been superimposed for this purpose.

The solid continuous line represents the Experimental condition. Known Concept is designated by the bar, or line of bars, and Distraction by a dot, or dotted line.

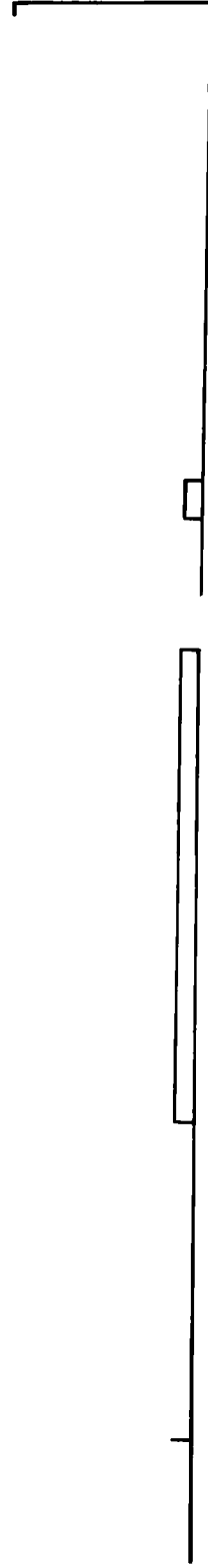
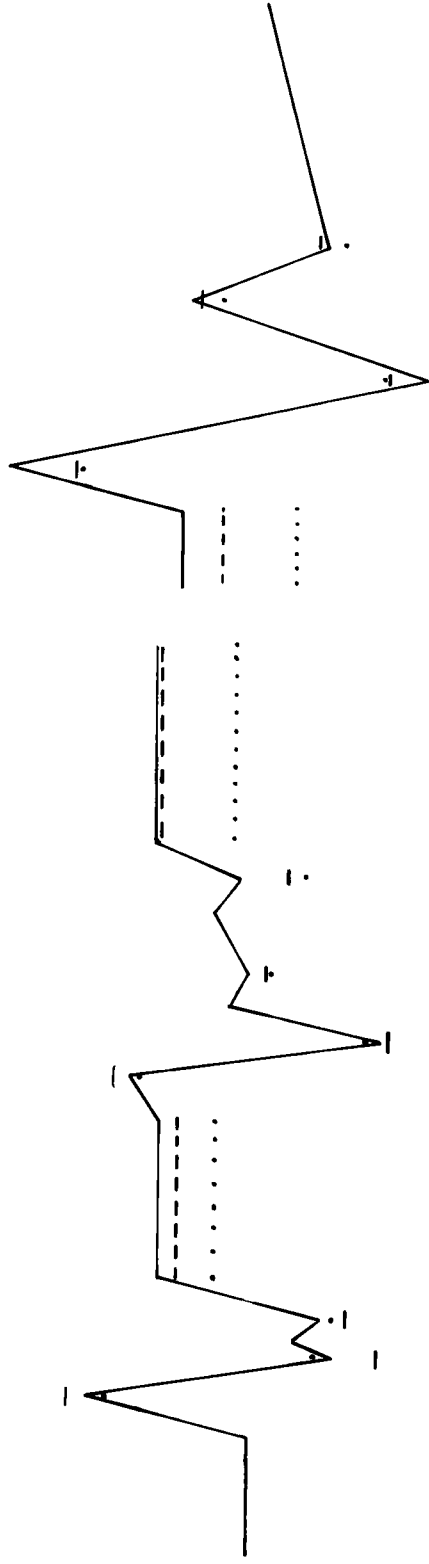
CZ PREINSIGHT



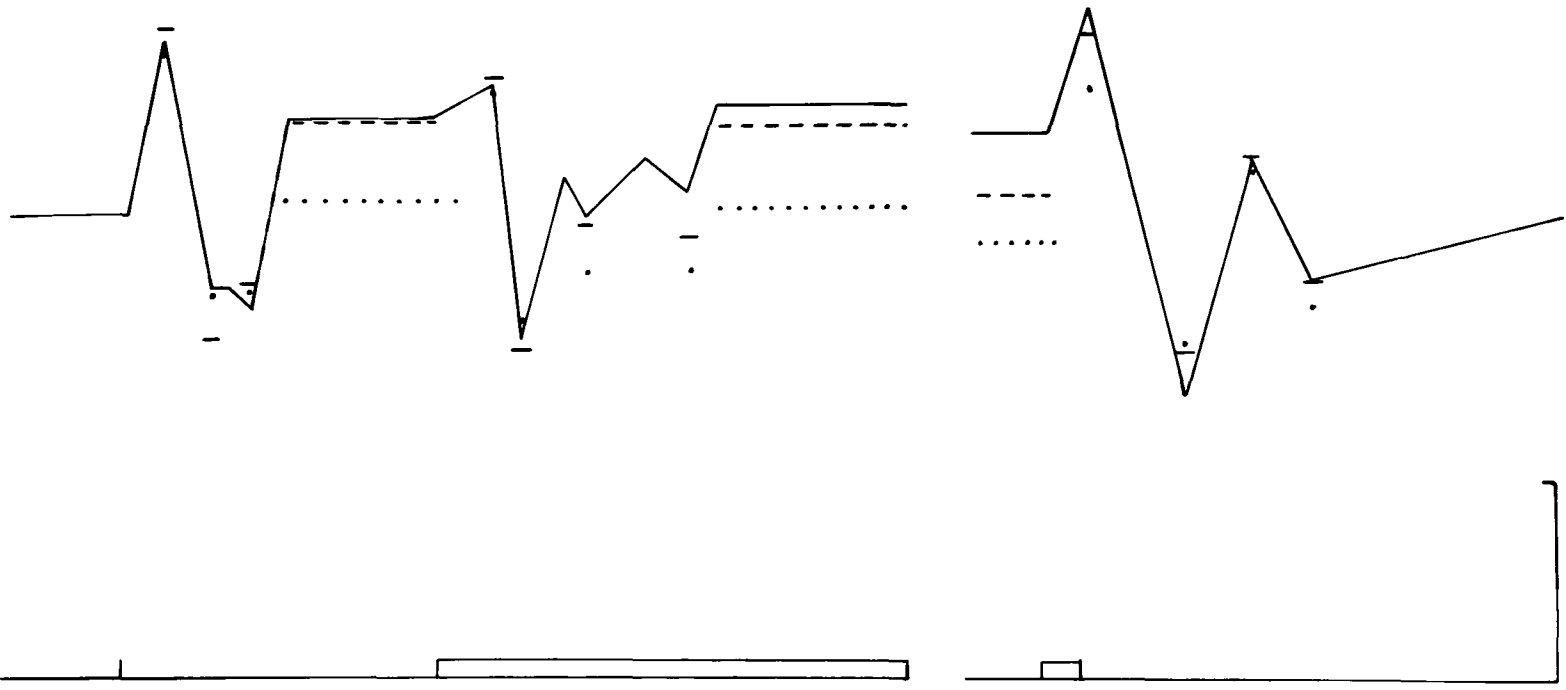
**CZ INSIGHT**



**CZ CONFIRM**



CZ OVERLEARN



CZ FALSE FEEDBACK

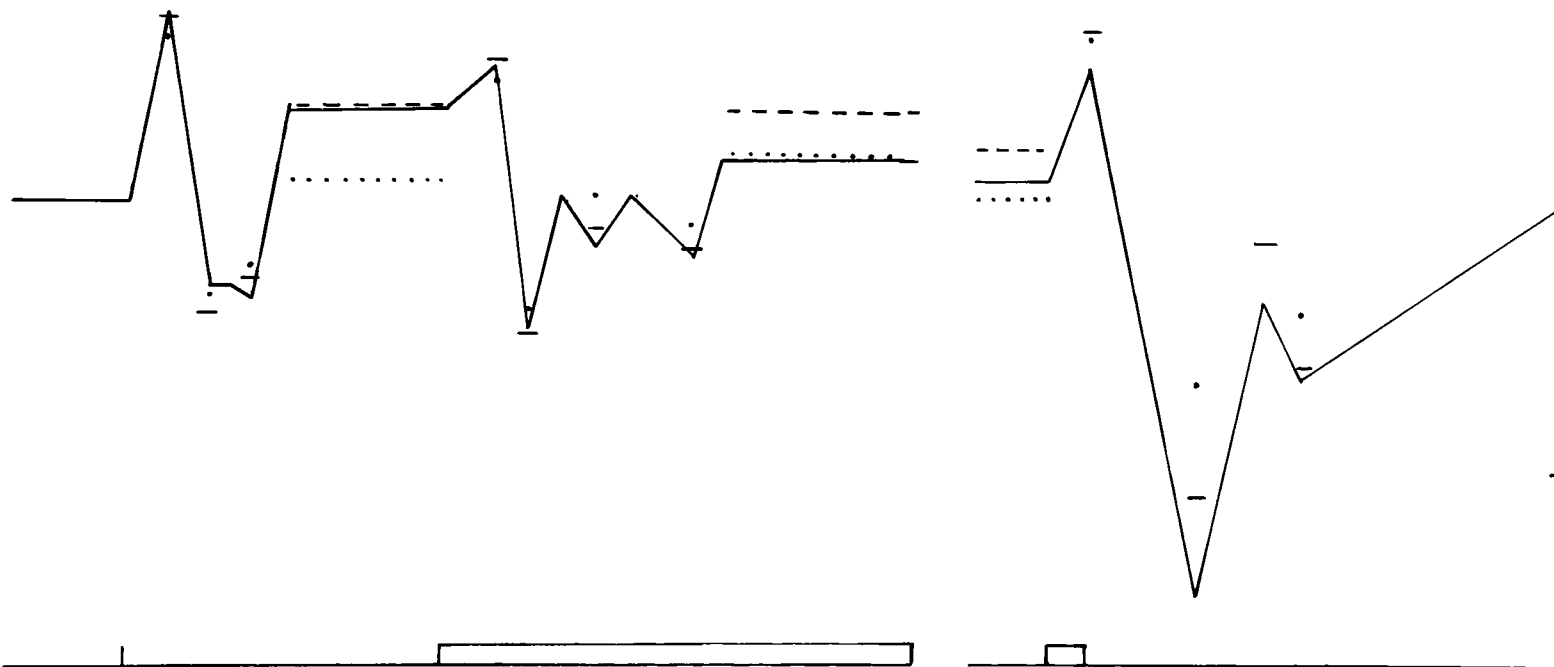


Table 5A

Analysis of Variance of CZ Baseline Offset  
for Five Levels of Stimulus Sequence  
(labelled Preinsight, Insight, Confirm,  
Overlearn and False Feedback) under  
Experimental (Learning), Known  
Concept, and Distraction Conditions

Source of Variation	<u>SS</u>	<u>df</u>	<u>MS</u>	<u>F</u>
A (Condition)	5.45	2	2.73	2.83
A x R (Replication) <sup>a</sup>	19.26	20	.96	
B (Sequence)	11.00	4	2.75	4.81*†
B x R	22.88	40	.57	
A x B <sup>b</sup>	16.64	8	2.08	2.14**††
A x B x R	77.93	80	.97	
R	55.34	10	5.53	

<sup>a</sup>To facilitate comprehension, the corresponding error term is presented along with the appropriate source of variation.

<sup>b</sup>Analysis of variance results for simple main effects for Baseline Offset are presented in Table 5B.

Conventional $F_{.99}$ (4,40) = 3.83	*Conventional $p$ .01
Conventional $F_{.95}$ (8,80) = 2.05	**Conventional $p$ .05
Conservative $F_{.90}$ (1,10) = 3.29	†Conservative $p$ .10
Conservative $F_{.75}$ (1,10) = 1.49	††Conservative $p$ .25

Table 5B

Analysis of Variance for Simple Main Effects  
Referring to Significant Interaction in Table 5A

Source of Variation	<u>SS</u>	<u>df</u>	<u>MS</u>	<u>F</u>
A at B				
A at b <sub>1</sub> (PINS)	1.14	2	.57	.59
A at b <sub>2</sub> (INS)	.50	2	.25	.26
A at b <sub>3</sub> (CON)	4.35	2	2.17	2.25
A at b <sub>4</sub> (OVER)	.12	2	.01	.01
A at b <sub>5</sub> (FFB)	15.97	2	7.98	8.25*
Pooled error			.97	
B at A				
B at a <sub>1</sub> (EXP)	14.36	4	3.59	4.29*
B at a <sub>2</sub> (KCPT)	9.86	4	2.47	2.95*
B at a <sub>3</sub> (DIST)	3.49	4	.87	1.05
Pooled error			.84	

NOTE. See page 88 of text for explanation of derivation of error term and F significance.

\*p < .05

sequence stage at each condition yielded no interaction for the Distraction control. For Known Concept, both FFB and OVER were significantly more negative than CON. For the Experimental condition, FFB was significantly more negative than all the other stages.

It was hypothesized that this rebound negativity was associated with performance evaluation, as if subjects were asking and answering questions about their results, and would probably occur after feedback. It was expected that this effect would be greatest in the Experimental condition, and that within this condition, FFB and PINS would necessitate the greatest evaluation of results. These expectations were partly confirmed. Although FFB was the only measurement significantly different from the others, PINS had the second largest negativity. It is also possible that the full rebound effect was not noted because of the inherent limitations of the time constant used.

The occurrence of this post-imperative negativity in the Known Concept condition may be related to the carry-over effect caused by the repeated measures design (Keppel, 1973). Subjects reported that the FFB high tone in the Known Concept condition disturbed them. This was most pronounced with the most experienced subjects. If so, the negativity here may be related to the evaluation of the feedback as being meaningless. The fact Known Concept FFB offset is not significantly different from many stages also suggests this possibility.

This increased post-imperative negativity obviously influenced the construction of the baseline to which all other measurements were made. What is of relevance is whether the effects to be noted with other measurements are due only to the offset changes. Arguments specifically related to independent measurements will be presented with those measurements. In general, however, Table 6 presenting the Pearson R correlation coefficients indicates that Baseline Offset is not linearly correlated with other measurements to a large degree, the maximum common variance with offset being approximately six percent, with Feedback P<sub>3</sub>. No correlations were significant at the .01 level of probability.

The significant condition results for Pre-slide CNV,  $F(2,20) = 20.20$ , conventional and conservative  $p < .01$ , suggests that this is a pure attentional-intentional effect (see Table 7). Both Experimental and Known Concept conditions were significantly more negative than the Distraction control. This was expected, as both Experimental and Known Concept demanded the same attention to the information inherent in the slide.

It had been suggested that the CNV in a learning task was a pre-stimulus set to attend and process information (Poon et al., 1974). These authors reported a decrease in CNV with overtraining, reflecting either the result of accumulated information, or decreased attention. The results of this present research yielded no learning differences, probably because the task was more demanding, and it was extremely difficult to become inattentive and maintain performance even after the concept was learned.

Table 6

Pearson R Correlation Coefficients of  
Baseline Offset with other Statistically  
Analyzed Variables, Measured at CZ  
in the Experimental Condition

Variables	Correlation with Baseline Offset
Pre-Slide CNV	-.12
Slide P <sub>3</sub> Amplitude	-.16
Slide P <sub>4</sub> Amplitude	-.21
Slide Slow Potential	-.14
Pre-Feedback CNV	.04
Feedback N <sub>1</sub> Amplitude	-.07
Feedback P <sub>3</sub> Amplitude	-.24
Feedback N <sub>3</sub> Amplitude	-.11
Feedback P <sub>4</sub> Amplitude	.08

Table 7

Analysis of Variance of CZ Pre-Slide CNV  
for Five Levels of Stimulus Sequence  
(labelled Preinsight, Insight, Confirm,  
Overlearn and False Feedback) under  
Experimental (Learning), Known  
Concept, and Distraction Conditions

Source of Variation	<u>SS</u>	<u>df</u>	<u>MS</u>	<u>F</u>
A (Condition)	20.26	2	10.13	20.20*†
A x R (Replication) <sup>a</sup>	10.03	20	.50	
B (Sequence)	.03	4	.01	0.02
B x R	11.26	40	.28	
A x B	1.08	8	.14	0.61
A x B x R	17.87	80	.22	
R	20.10	10	2.01	

<sup>a</sup>To facilitate comprehension, the corresponding error term is presented along with the appropriate source of variation.

Conventional  $F_{.99}$  (2,20) = 5.85 \*Conventional  $p < .01$

Conservative  $F_{.99}$  (1,10) = 10.00 †Conservative  $p < .01$

Significant interaction effects (see Tables 8A & 8B) were noted for the Slide Slow Potential (SSP),  $F(8,80) = 3.46$ , conventional  $p < .01$ , Conservative  $p < .10$ . For INS, CON, and OVER, both the Experimental and Known Concept Control conditions were significantly more negative than Distraction. For FFB Experimental was significantly greater than the other two conditions, while for PINS, Known Concept was significantly more negative than Distraction and Experimental conditions. The sensory slow potential being controlled for by the Distraction condition (Keidel, 1972), the differences may possibly reflect intentional engagement in the task, plus the known processing of information in the slide. In general, it was expected that both Known Concept and Experimental would be equivalent (as in INS, CON, OVER), since essentially the same processing was occurring.

It should be noted that the Readiness Potential (Gilden, Vaughan & Costa, 1966) possibly plays a major part in these differences, as there was no motor response for the Distraction control.

Within the conditions, there was a general tendency for FFB and PINS to be significantly less negative (OVER > FFB, PINS; CON > FFB, PINS; INS > FFB). No differences were noted with Known Concept, although in the Distraction condition, FFB was significantly more negative than OVER. This last result was attributed to chance.

It is difficult to assess the SSP differences in FFB and PINS. One considered possibility was that this was a reflection of experimental anxiety (Knott & Irwin, 1968; Low & Swift, 1971). This, however, was not

Table 8A

Analysis of Variance of CZ Slide Slow Potential  
for Five Levels of Stimulus Sequence  
(labelled Preinsight, Insight, Confirm,  
Overlearn and False Feedback), under  
Experimental (Learning), Known  
Concept, and Distraction Conditions

Source of Variation	<u>SS</u>	<u>df</u>	<u>MS</u>	<u>F</u>
A (Condition)	21.26	2	10.63	16.92*†
A x R (Replication) <sup>a</sup>	12.57	20	.63	
B (Sequence)	.86	4	.22	1.22
B x R	7.12	40	.18	
A x B <sup>b</sup>	5.98	8	.75	3.46*††
A x B x R	17.27	80	.22	
R	16.17	10	1.62	

<sup>a</sup>To facilitate comprehension, the corresponding error term is presented along with the appropriate source of variation.

<sup>b</sup>Analysis of variance results for simple main effects for Slide Slow Potential are presented in Table 8B.

Conventional  $F_{.99} (2,20) = 5.85$   
Conventional  $F_{.99} (8,80) = 2.74$

\*Conventional  $p < .01$

Conservative  $F_{.99} (1,10) = 10.00$   
Conservative  $F_{.90} (1,10) = 3.29$

†Conservative  $p < .01$   
††Conservative  $p < .10$

Table 8B

Analysis of Variance for Simple Main Effects  
Referring to Significant Interaction in Table 8A

Source of Variance	<u>SS</u>	<u>df</u>	<u>MS</u>	<u>F</u>
A at B				
A at b <sub>1</sub> (PINS)	3.90	2	1.95	6.46*
A at b <sub>2</sub> (INS)	6.67	2	3.34	11.05*
A at b <sub>3</sub> (CON)	6.30	2	3.15	10.43*
A at b <sub>4</sub> (OVER)	8.61	2	4.30	14.25*
A at b <sub>5</sub> (FFB)	1.78	2	.89	2.95
Pooled error			.30	
B at A				
B at a <sub>1</sub> (EXP)	5.05	4	1.26	6.11*
B at a <sub>2</sub> (KCPT)	.43	4	.11	.52
B at a <sub>3</sub> (DIST)	1.37	4	.34	1.66*
Pooled error			.21	

NOTE. See page 88 of text for explanation of derivation of error term and F significance.

\*p < .05

reflected in Pre-slide CNV. The small SSP for FFB and PINS may be due to some extent to baseline offset. It may also be that the SSP is exhibiting some type of ceiling effect with parts of the learning sequence demanding most processing.

The final slow potential variation occurred with Pre-feedback CNV (see Table 9), where the only significance came in the condition factor,  $F(2,20) = 12.21$ , conventional and conservative  $p < .01$ . Both the processing conditions were significantly more negative than Distraction. The reason no significant differences existed between the Experimental and Known Concept conditions may be that the random location of the high tone with Known Concept may have led to some expectation and attention as to when the tone would change. In a sense this was parodying the attentional-intentional engagement of the Experimental condition. In addition, the Known Concept feedback gave information as to the timing of the response; i.e., if the button press did not fall within the response contingency time, no feedback was given.

Statistics show no significant results common to all subjects for the amplitudes of Slide P<sub>3</sub> and P<sub>4</sub>. It may be that these results were obscured by the SSP, and that a multivariate analysis is needed to uncover the possible relevance of these measurements. It is of some interest to note that several subjects had a very distinct P<sub>4</sub> component to slide onset, an example of which is seen in the top average of Figure 6.

Table 9

Analysis of Variance of CZ Pre-Feedback CNV  
for Five Levels of Stimulus Sequence  
(labelled Preinsight, Insight, Confirm,  
Overlearn and False Feedback) under  
Experimental (Learning), Known  
Concept, and Distraction Conditions

Source of Variation	<u>SS</u>	<u>df</u>	<u>MS</u>	<u>F</u>
A (Condition)	23.78	2	11.89	12.21* †
A x R (Replication) <sup>a</sup>	19.48	20	.97	
B (Sequence)	2.24	4	.56	1.94
B x R	11.51	40	.29	
A x B	6.03	8	.75	2.36
A x B x R	25.53	80	.32	
R	13.36	10	1.34	

<sup>a</sup>To facilitate comprehension, the corresponding error term is presented along with the appropriate source of variation.

Conventional  $F_{.99}$  (2,20) = 5.85      \*Conventional  $p < .01$

Conservative  $F_{.99}$  (1,10) = 10.00      †Conservative  $p < .01$

The meaning of a Slide P4 is tenuous. It may be that it is an indication of effective feedback return (Picton & Low, 1971), and appears with a confidence in a decision even during presentation of task information.

A sequence effect was the only significant  $F$  ratio  $\{F(4,40) = 4.14, \text{conventional } p < .01, \text{conservative } p < .10\}$  for Feedback  $N_1$  amplitude (see Table 10A), with CON being significantly larger than FFB. This appears to reflect stimulus related changes independent of attention and learning (see Figure 13). An examination of the mean scores suggest that the incorrect feedback, with a stimulus frequency of 4 KHZ, was less than the  $N_1$  amplitude related with good feedback, with a stimulus frequency of 1 KHZ. This difference appears to be determined by the frequency stimulus parameters, in the pattern noted by others (Davis et al., 1968; Rothman, 1970).

Although there were no significant attention effects, these results do not necessarily mitigate against this concept of the function of  $N_1$  (Hillyard et al., 1973; Picton et al., 1971). An examination of the results with a lower level of significance for the interaction  $\{F(8,80) = 2.75, \text{conventional } p < .01, \text{conservative } p < .25\}$  reveals that at least in some sequences (CON, OVER), the Experimental condition had a significantly larger  $N_1$ , and within CON, Experimental  $N_1$  was significantly larger than both other conditions (see Table 10B). This interpretation is marred by the lack of significant results within the Known Concept condition,

Table 10A

Analysis of Variance of CZ Feedback N<sub>1</sub> Amplitude  
for Five Levels of Stimulus Sequence  
(labelled Preinsight, Insight, Confirm,  
Overlearn and False Feedback) under  
Experimental (Learning), Known  
Concept, and Distraction Conditions

Source of Variation	<u>SS</u>	<u>df</u>	<u>MS</u>	<u>F</u>
A (Condition)	4.87	2	2.43	2.00
A x R (Replication) <sup>a</sup>	24.30	20	1.21	
B (Sequence)	7.61	4	1.90	4.14* †
B x R	18.39	40	.46	
A x B <sup>b</sup>	8.41	8	1.05	2.75* ††
A x B x R	30.58	80	.38	
R	35.41	10	3.54	

<sup>a</sup>To facilitate comprehension, the corresponding error term is presented along with the appropriate source of variation.

<sup>b</sup>Analysis of variance results for simple main effects for Feedback N<sub>1</sub> Amplitude are presented in Table 10B.

Conventional  $F_{.99} (4,40) = 3.83$   
Conventional  $F_{.99} (8,80) = 2.74$

\*Conventional  $p < .01$

Conservative  $F_{.90} (1,10) = 3.29$   
Conservative  $F_{.75} (1,10) = 1.49$

†Conservative  $p < .10$   
††Conservative  $p < .75$

Table 10B

Analysis of Variance for Simple Main Effects  
Referring to Significant Interaction in Table 10A

Source of Variance	<u>SS</u>	<u>df</u>	<u>MS</u>	<u>F</u>
A at B				
A at b <sub>1</sub> (PINS)	.36	2	.18	.33
A at b <sub>2</sub> (INS)	1.42	2	.71	1.30
A at b <sub>3</sub> (CON)	5.63	2	2.82	5.16*
A at b <sub>4</sub> (OVER)	4.75	2	2.38	4.35*
A at b <sub>5</sub> (FFB)	1.12	2	.56	1.03
Pooled error			.55	
B at A				
B at a <sub>1</sub> (EXP)	13.54	4	3.38	8.32*
B at a <sub>2</sub> (KCPT)	.32	4	.08	.20
B at a <sub>3</sub> (DIST)	2.14	4	.54	1.32*
Pooled error			.41	

NOTE. See page 88 of text for explanation of derivation of error term and F significance.

\*p <.05

for it was expected that stimulus frequency would have a similar effect as reported above. It is also interesting to speculate why, even at this level of significance, there were no significant  $N_1$  interaction effects for FFB, PINS and INS.

Statistical analysis of  $P_3$  amplitude to feedback yielded significant interaction effects,  $F(8,80) = 4.95$ , conventional  $p < .01$ , conservative  $p < .05$  (see Tables 11A and 11B). Testing of the simple main effects suggests a possible triple definition of the psychological significance of this evoked potential component: amount of data processing; meaningfulness or task relevance of the learning process; and novelty or possible carry-over effects.

When the conditions are considered at each sequence stage, the Experimental condition is significantly greater than both other conditions at FFB, PINS, and INS, the Distraction condition being the smallest. Moreover, for FFB and PINS, Known Concept is also significantly greater than Distraction.

It appears that there is a continuum related to the amount of information processing. The Distraction condition, with supposedly no processing occurring relevant to the stimuli, is smallest. Known Concept has some processing to accomplish, since an answer was required. There would be some interest in, and evaluation of, the feedback signal, as previously noted with Baseline Offset. The Experimental condition had obviously the greatest amount of post-feedback processing to accomplish.

Table 11A

Analysis of Variance of CZ Feedback P<sub>3</sub> Amplitude  
for Five Levels of Stimulus Sequence  
(labelled Preinsight, Insight, Confirm,  
Overlearn and False Feedback) under  
Experimental (Learning), Known  
Concept, and Distraction Conditions

Source of Variation	<u>SS</u>	<u>df</u>	<u>MS</u>	<u>F</u>
A (Condition)	69.64	2	34.82	19.96* †
A x R (Replication) <sup>a</sup>	34.90	20	1.74	
B (Sequence)	56.24	4	14.06	17.61* †
B x R	31.93	40	.80	
A x B <sup>b</sup>	24.43	8	3.05	4.96* ††
A x B x R	49.48	80	.62	
R	73.67	10	7.37	

<sup>a</sup>To facilitate comprehension, the corresponding error term is presented along with the appropriate source of variation.

<sup>b</sup>Analysis of variance results for simple main effects for Feedback P<sub>3</sub> Amplitude are presented in Table 11B.

Conventional  $F_{.99}$  (2,20) = 5.85  
Conventional  $F_{.99}$  (4,40) = 3.83  
Conventional  $F_{.99}$  (8,80) = 2.74

\*Conventional  $p < .01$

Conservative  $F_{.99}$  (1,10) = 10.00  
Conservative  $F_{.95}$  (1,10) = 4.96

†Conservative  $p < .01$   
††Conservative  $p < .05$

Table 11B

Analysis of Variance for Simple Main Effects  
Referring to Significant Interaction in Table 11A

Source of Variation	<u>SS</u>	<u>df</u>	<u>MS</u>	<u>F</u>
A at B				
A at b <sub>1</sub> (PINS)	42.14	2	21.07	24.91*
A at b <sub>2</sub> (INS)	19.04	2	9.52	11.21*
A at b <sub>3</sub> (CON)	1.75	2	.88	1.04
A at b <sub>4</sub> (OVER)	1.94	2	.97	1.14
A at b <sub>5</sub> (FFB)	28.98	2	14.49	17.13*
Pooled error			.85	
B at A				
B at a <sub>1</sub> (EXP)	43.74	4	10.94	16.08*
B at a <sub>2</sub> (KCPT)	26.09	4	6.52	9.59*
B at a <sub>3</sub> (DIST)	10.94	4	2.74	4.02*
Pooled error			.68	

NOTE. See page 88 of text for explanation of derivation of error term and F significance.

\*p < .01

This concept corroborates several other proposals of a larger P<sub>3</sub> with increased cognitive processing demands (Donchin et al., 1973; Poon et al., 1974, 1976).

Disconfirming feedback appears to require greater cortical involvement than confirming feedback. This is the case regardless of the probability of occurrence of disconfirming feedback. If a subject erred 75% or 25% of the times, the amplitude of the P<sub>3</sub> component evoked to the feedback signal remained constantly large (K. Campbell, personal communication).

It may also be that differing degrees of attention are the basis of the differences between conditions (Corby & Kopell, 1973; Donchin & Cohen, 1967; Nash & Singer, 1974). Although this may be a factor, the fact that there was no significant difference between the Experimental and Known Concept Pre-feedback CNV mitigates against the possibility that it is totally an attention effect.

The second factor apparently affecting P<sub>3</sub> amplitude is the task relevance or meaningfulness of the stimulus, which was seemingly determined by learning. This was noted when the sequence stages were compared within each condition. Within the Experimental condition, FFB P<sub>3</sub> was significantly larger than all other sequence stages. Both PINS and INS, in that order, were significantly greater than CON and OVER. This is schematically illustrated in Figure 13.

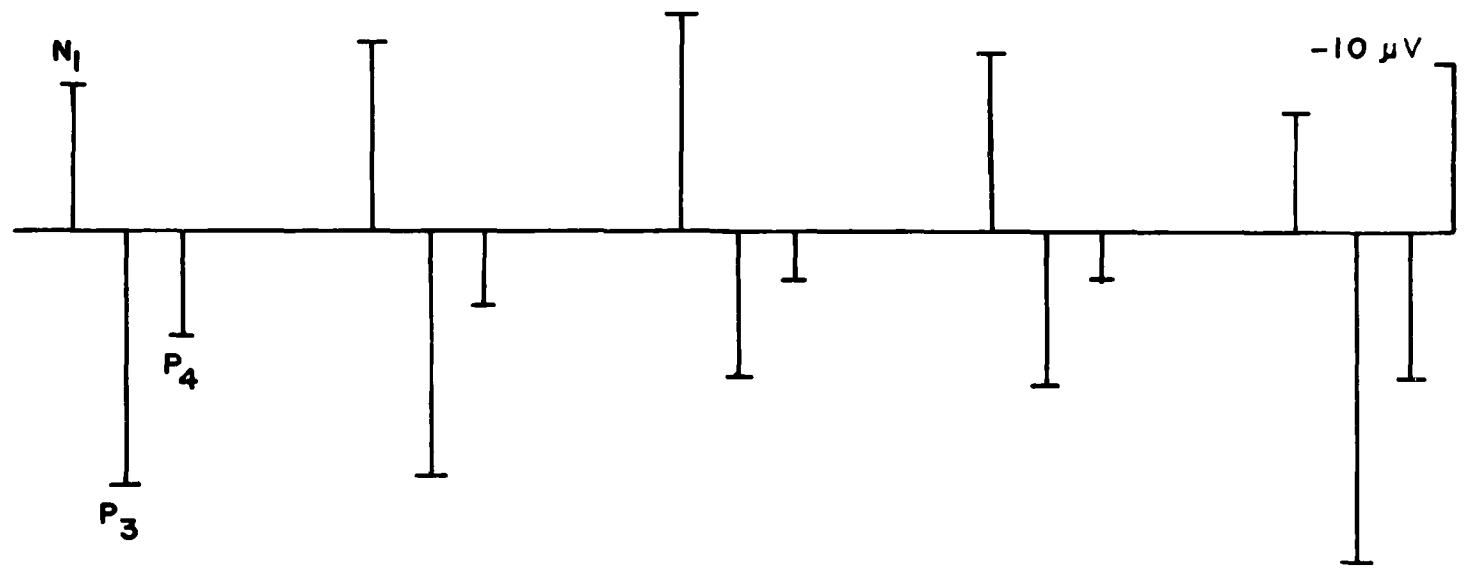
It appears, then, that the P<sub>3</sub> to feedback is directly related to the meaningfulness and task relevance of the feedback stimulus, and that this level of meaningfulness is determined by the learning process.

Figure 13

Bar Graph Representation of Feedback Response Across  
the Five Levels of Stimulus Sequence  
Within the Experimental Condition

A classic example of the P<sub>3</sub>, P<sub>4</sub> variation to feedback response in a concept learning process was noted in a pilot study with Subject K.C. (averages of 10 or multiples of 10). Under this example is a bar graph indexing the mean evoked potential measurements for N<sub>1</sub>, P<sub>3</sub>, and P<sub>4</sub> across the five stages of stimulus sequence (or learning process) within the Experimental condition only.

# CZ FEEDBACK RESPONSE



It is possible to associate the meaningfulness and P<sub>3</sub> enhancement with other theoretical proposals. The learning process may alter the salience, or subjective importance, of the feedback (Paul & Sutton, 1972; Sutton et al., 1965; Sutton et al., 1967). Other models have suggested that meaningfulness is connected with confidence in a decision (Benson & Teas, 1972; Hillyard, 1969; Hillyard et al., 1971), regardless of the correctness of the decision (Squires et al., 1973-b).

Because of the possible differences in electrophysiological correlates that may depend on the type of task (Squires et al., 1973-b), it seems more parsimonious to stay as much as possible within the realm of higher order learning. As such, these results corroborate results from other learning paradigms, in that acquisition P<sub>3</sub>s are greater than overlearn, and incorrect feedback yielded larger P<sub>3</sub> amplitudes than correct (Jeness, 1972; Poon et al., 1974). In a learning situation, incorrect trials may reflect the sign of a flaw in one's hypothesis, and a consequent need to generate a new hypothesis. Correct feedback merely confirms existing modes of problem solving.

The third possibility of P<sub>3</sub> enhancement is novelty, and the orienting response (Ford et al., 1976; Squires, N. et al., 1975; Vaughan & Ritter, 1970). This was speculated when it was noted that, in the Known Concept condition, FFB P<sub>3</sub> was significantly larger than the other conditions. However, this did not occur in the Distraction condition. It may also be that the high tone had acquired a conditioned valence,

resulting in a carry-over effect. The fact that PINS was significantly larger than CON and OVER only in the Experimental condition suggests that, even if novelty is a factor, it is not the only factor.

One P<sub>3</sub> result that appeared to be due to chance was a PINS Feedback P<sub>3</sub> significantly smaller than all other sequences within the Distraction condition. It should be noted that there appears to be a reciprocal relationship of Slide Slow Potential and Feedback P<sub>3</sub>. When a concept is learned, FB P<sub>3</sub> decreases and SSP increases. This result may be congruent with the smaller CNV associated with the increased cognitive processing demands (Delse et al., 1972; Poon et al., 1974, 1976).

In view of the possible problems with baseline distorting true Feedback P<sub>3</sub> effects, N<sub>1</sub> - P<sub>3</sub> peak to peak measurements were analyzed (see Table 12). The results were in strong corroboration of the P<sub>3</sub> results alone. The Experimental condition was significantly larger than both other conditions, while Known Concept also differed significantly from the Distraction control. FFB is significantly greater than all other stages, while PINS was also significantly larger than OVER and INS.

Statistical significant interaction {  $F(8,80) = 3.72$ , conventional  $p < .01$ , conservative  $p < .10$  } was noted with the P<sub>4</sub> late positive wave occurring after feedback (see Tables 13A & 13B; and Figure 13). Differences in the conditions were observed only with FFB and PINS, where Experimental condition was significantly greater than Distraction.

Table 12

Analysis of Variance of CZ N<sub>1</sub> - P<sub>3</sub> Peak to Peak Amplitude  
for Five Levels of Stimulus Sequence  
(labelled Preinsight, Insight, Confirm,  
Overlearn and False Feedback) under  
Experimental (Learning), Known  
Concept, and Distraction Conditions

Source of Variation	<u>SS</u>	<u>df</u>	<u>MS</u>	<u>F</u>
A (Condition)	109.84	2	54.92	25.28* †
A x R (Replication) <sup>a</sup>	43.44	20	2.17	
B (Sequence)	39.75	4	9.94	14.23* †
B x R	27.36	40	.68	
A x B	13.38	8	1.67	2.57
A x B x R	52.01	80	.65	
R	111.84	10		

<sup>a</sup>To facilitate comprehension, the corresponding error term is presented along with the appropriate source of variation.

Conventional  $F_{.99}$  (2,20) = 5.85  
Conventional  $F_{.99}$  (4,40) = 3.83

\*Conventional  $p < .01$

Conservative  $F_{.99}$  (1,10) = 10.00

†Conservative  $p < .01$

Table 13A

Analysis of Variance of CZ Feedback P<sub>4</sub> Amplitude  
for Five Levels of Stimulus Sequence  
(labelled Preinsight, Insight, Confirm,  
Overlearn and False Feedback) under  
Experimental (Learning), Known  
Concept, and Distraction Conditions

Source of Variation	<u>SS</u>	<u>df</u>	<u>MS</u>	<u>F</u>
A (Condition)	2.76	2	1.38	1.70
A x R (Replication) <sup>a</sup>	16.29	20	.81	
B (Sequence)	21.63	4	5.41	5.40* †
B x R	40.08	40	1.00	
A x B <sup>b</sup>	8.04	8	1.00	3.72* ††
A x B x R	21.62	80	.27	
R	38.26	10		

<sup>a</sup>To facilitate comprehension, the corresponding error term is presented along with the appropriate source of variation.

<sup>b</sup>Analysis of variance results for simple main effects for Feedback P<sub>4</sub> Amplitude are presented in Table 13B.

Conventional  $F_{.99} (4,40) = 3.83$   
Conventional  $F_{.99} (8,80) = 2.74$

\*Conventional  $p < .01$

Conservative  $F_{.95} (1,10) = 4.96$   
Conservative  $F_{.90} (1,10) = 3.29$

† Conservative  $p < .05$   
†† Conservative  $p < .10$

Table 13B

Analysis of Variance for Simple Main Effects  
Referring to Significant Interaction in Table 13A

Source of Variance	<u>SS</u>	<u>df</u>	<u>MS</u>	<u>F</u>
A at B				
A at b <sub>1</sub> (PINS)	4.93	2	2.47	6.53*
A at b <sub>2</sub> (INS)	1.12	2	.56	1.49
A at b <sub>3</sub> (CON)	.67	2	.34	.89
A at b <sub>4</sub> (OVER)	.82	2	.41	1.09
A at b <sub>5</sub> (FFB)	3.27	2	1.64	4.33*
Pooled error				
B at A				
B at a <sub>1</sub>	11.82	4	2.95	5.75*
B at a <sub>2</sub> (KCPT)	14.11	4	3.53	6.87*
B at a <sub>3</sub> (DIST)	3.75	4	.94	1.83*
Pooled error				

NOTE. See page 88 of text for explanation of derivation of error term and F significance.

\*  $p < .01$

With FFB, Known Concept was also significantly greater than Distraction but not from the Experimental condition, with PINS, the Experimental had a significantly more positive P<sub>4</sub> wave than both other conditions. Although this combination suggests that the FFB P<sub>4</sub> to the Known Concept condition is also a conditioned effect, the possible relevance of P<sub>4</sub> was noted in PINS where Experimental was significantly greater than both other conditions.

P<sub>4</sub> obfuscation by carry-over effects was also suggested by the observations that subjects who generated Feedback P<sub>4</sub> waves to the Known Concept and Distraction conditions stated that they were bothered or disturbed by the supposedly meaningless high tone. They felt they were reflexly attributing meaning to something they had been instructed previously to regard as irrelevant.

The existence of significant differences in P<sub>4</sub> only with FFB and PINS suggests that this late positive wave is mainly related to incorrect feedback, and errors in learning. It was also observed that the P<sub>4</sub> decreased with familiarity and competence in the task, possibly indicating that this relatively new evoked potential component is a true "learning" wave. One subject who did not have a clear, discernible P<sub>4</sub> reported that performing the task was like driving a car and not being aware of stopping for the red light. His performance, nevertheless, was very high. His results from the pilot study during which he was not so familiar with the task did reveal an evident feedback P<sub>4</sub>.

When a subject was unable to learn the correct concept over an extended period, the  $P_4$  was enhanced (see Figure 14). Individuals who did not have very clear  $P_4$ s for ordinary averages inevitably had them during this series of continuous errors. It may be that the  $P_4$  is a "learning to learn" wave.

When the sequence stages were examined at each condition, FFB  $P_4$  was significantly larger than all other sequences in both Experimental and Known Concept conditions. In the Distraction control, FFB was significantly larger than PINS.

It appears again that  $P_4$  differences may be affected by the offset effect. In addition to the low Pearson  $R$ , other arguments rally against this possibility. In the Experimental condition, PINS has the second largest  $P_4$ , while in both other conditions, it is the smallest measurement.

It was decided to examine the Feedback  $P_4$  at the OZ cortical electrode site, where its amplitude was very large, and no significant offset effect existed to obscure the results. Statistical analysis of Feedback  $P_4$  at OZ (see Tables 14A & 14B) yielded a significant interaction effect,  $F(8,80) = 3.88$ , conventional  $p < .01$ , conservative  $p < .10$ . Within sequence stages, there were significant simple main effects only with FFB, PINS and INS. In INS and FFB, both the Experimental and Known Concept conditions were significantly greater than Distraction, but not significantly different from each other. In PINS, Experimental was significantly more positive than both other conditions.

Figure 14

## Feedback Response to Continuous Error

Seven subjects were, at one time or another, unable to achieve the correct underlying concept within one series or more. The averaged feedback responses to these continuous errors (labelled "wipeout") revealed P<sub>3</sub> and P<sub>4</sub> waves that were enhanced in their respective areas of maximum scalp distribution. This enhancement was relative to each subject. Thus, subjects who had a small P<sub>4</sub> even to False Feedback developed a larger P<sub>4</sub> under conditions of continuous error.

# FEEDBACK RESPONSE TO CONTINUOUS ERROR

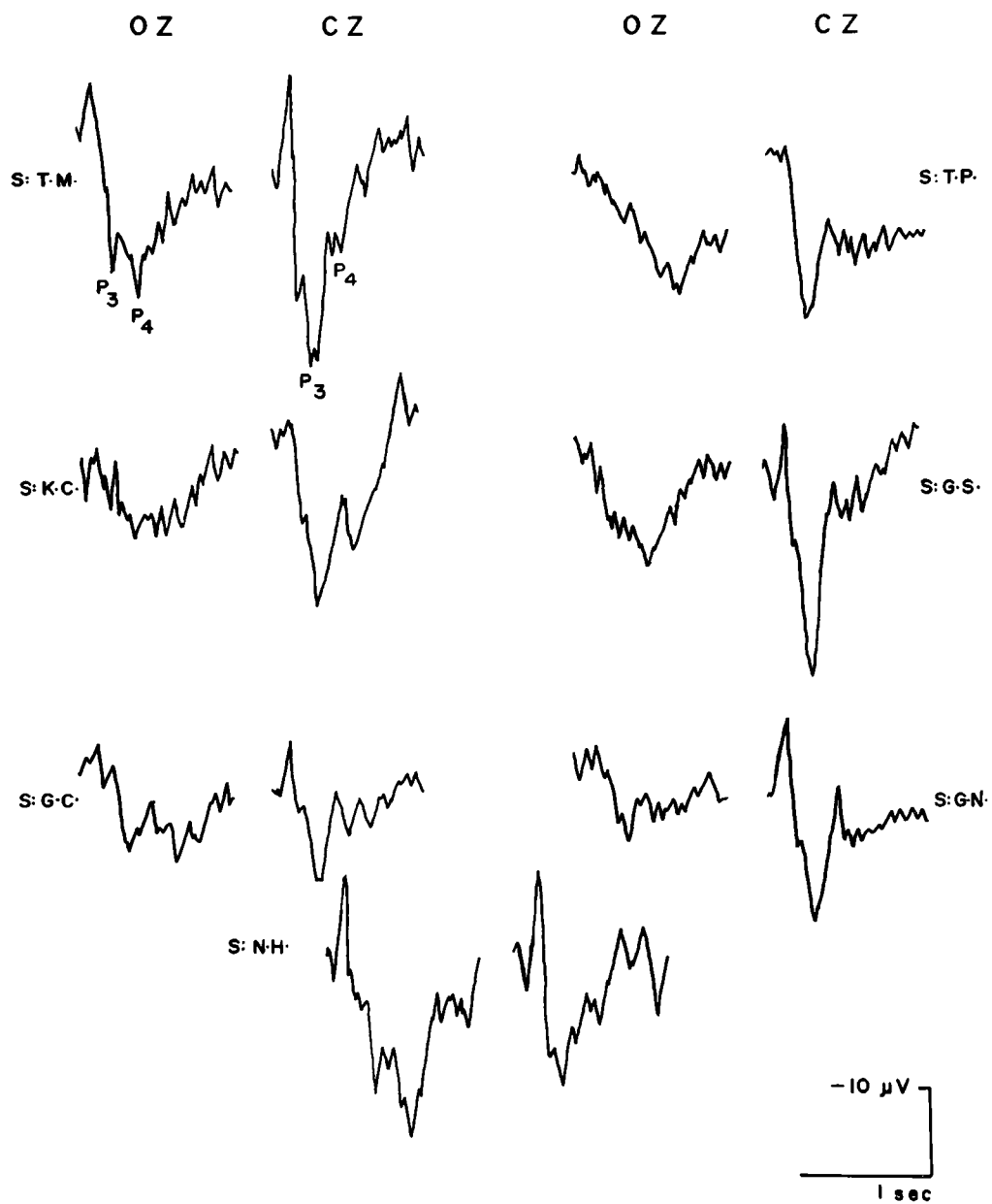


Table 14A

Analysis of Variance of OZ Feedback P<sub>4</sub>  
for Five Levels of Stimulus Sequence  
(labelled Preinsight, Insight, Confirm,  
Overlearn and False Feedback) under  
Experimental (Learning), Known  
Concept, and Distraction Conditions

Source of Variation	<u>SS</u>	<u>df</u>	<u>MS</u>	<u>F</u>
A (Condition)	4.92	2	2.46	2.63
A x R (Replication) <sup>a</sup>	18.72	20	.99	
B (Sequence)	8.09	4	2.02	4.27*†
B x R	18.95	40	.47	
A x B <sup>b</sup>	9.71	8	1.21	3.88*†
A x B x R	25.03	80	.31	
R	65.81	10	6.58	

<sup>a</sup>To facilitate comprehension, the corresponding error term is presented along with the appropriate source of variation.

<sup>b</sup>Analysis of variance results for simple main effects for OZ Feedback P<sub>4</sub> are presented in Table 14B.

Conventional  $F_{.99} (4,40) = 3.83$   
Conventional  $F_{.99} (8,80) = 2.74$

\*Conventional  $p < .01$

Conservative  $F_{.90} (1,10) = 3.29$

†Conservative  $p < .10$

Table 14B

Analysis of Variance for Simple Main Effects  
Referring to Significant Interaction in Table 14A

Source of Variation	<u>SS</u>	<u>df</u>	<u>MS</u>	<u>F</u>
A at B				
A at b <sub>1</sub> (PINS)	3.37	2	1.68	3.86*
A at b <sub>2</sub> (INS)	2.95	2	1.47	3.38*
A at b <sub>3</sub> (CON)	.68	2	.34	.78
A at b <sub>4</sub> (OVER)	.17	2	.09	.19
A at b <sub>5</sub> (FFB)	7.47	2	3.74	8.58*
Pooled error			.44	
B at A				
B at a <sub>1</sub> (EXP)	11.40	4	2.85	7.85*
B at a <sub>2</sub> (KCPT)	5.23	4	1.31	3.60*
B at a <sub>3</sub> (DIST)	1.27	4	.32	.87
Pooled error			.36	

NOTE. See page 88 of text for explanation of derivation of error term and F significance.

\*p .05

When considered according to conditions, significant simple main effects existed only within the Experimental condition. FFB  $P_4$  was significantly greater than CON, OVER, and INS; PINS > CON, OVER; and INS > CON.

It appears then that the Feedback  $P_4$  is a phenomenon related in some way to learning and information processing during the three learning stages of the Experimental process: FFB, PINS and INS. The example in Figure 13, using Experimental pilot data not included in the statistical analysis, presents an excellent profile on FFB  $P_4$  fluctuations with learning. With a change in concept (FFB),  $P_4$  to feedback is largest, diminishing in size until almost absent in CON and OVER.

Feedback  $N_3$  results were basically similar to  $P_4$  (see Tables 15A & 15B) with a significant interaction effect,  $F(8,80) = 4.93$ , conventional  $p < .01$ , conservative  $p < .10$ . Within both FFB and PINS, Distraction was significantly greater (more negative) than both other conditions, and Known Concept was significantly more negative than the Experimental condition. When the learning process was considered at each condition, no significant differences in the Distraction control were noted. For the other two conditions, FFB was significantly smaller (more positive) than all other stages. Within Experimental alone, PINS was significantly more positive than CON and OVER.

It may be that there is a  $N_3 - P_4$  complex related to information processing, a possibility suggested by the observation that at least two

Table 15A

Analysis of Variance of CZ Feedback N<sub>3</sub> Amplitude  
for Five Levels of Stimulus Sequence  
(labelled Preinsight, Insight, Confirm,  
Overlearn and False Feedback) under  
Experimental (Learning), Known  
Concept, and Distraction Conditions

Source of Variation	<u>SS</u>	<u>df</u>	<u>MS</u>	<u>F</u>
A (Condition)	12.15	2	6.08	6.76* †
A x R (Replication) <sup>a</sup>	17.99	20	.90	
B (Sequence)	19.26	4	4.81	4.50* ††
B x R	42.83	40	1.07	
A x B <sup>b</sup>	18.49	8	2.31	4.93* †
A x B x R	37.55	80	.47	
R	42.11	10	4.21	

<sup>a</sup>To facilitate comprehension, the corresponding error term is presented along with the appropriate source of variation.

<sup>b</sup>Analysis of variance results for simple main effects for Feedback N<sub>3</sub> Amplitude are presented in Table 15B.

Conventional  $\bar{F}_{.99}$  (2,20) = 5.85  
Conventional  $\bar{F}_{.99}$  (4,40) = 3.83  
Conventional  $\bar{F}_{.99}$  (8,80) = 2.74

\*Conventional  $p < .01$

Conservative  $\bar{F}_{.95}$  (1,10) = 4.96  
Conservative  $\bar{F}_{.90}$  (1,10) = 3.29

†Conservative  $p < .05$   
††Conservative  $p < .10$

Table 15B

Analysis of Variance for Simple Main Effects  
Referring to Significant Interaction in Table 15A

Source of Variance	<u>SS</u>	<u>df</u>	<u>MS</u>	<u>F</u>
A at B				
A at b <sub>1</sub> (PINS)	10.58	2	5.29	9.51*
A at b <sub>2</sub> (INS)	1.92	2	.96	1.72
A at b <sub>3</sub> (CON)	.65	2	.33	.59
A at b <sub>4</sub> (OVER)	.04	2	.02	.03
A at b <sub>5</sub> (FFB)	17.46	2	8.73	15.70*
Pooled error			.56	
B at A				
B at a <sub>1</sub> (EXP)	25.78	4	6.44	9.62*
B at a <sub>2</sub> (KCPT)	10.19	4	2.54	3.79*
B at a <sub>3</sub> (DIST)	1.90	4	.48	.71
Pooled error			.67	

NOTE. See page 88 of text for explanation of derivation of error term and F significance.

\*p < .05

subjects who had small Feedback P<sub>4</sub> waves had large N<sub>3</sub> waves. More probably, the N<sub>3</sub> is being affected by a larger underlying positivity (Poon et al., 1976; Squires, N. et al., 1975).

Although CZ latency measures in the Experimental condition were not statistically analyzed, a visual examination of the data (see Table 16) shows that Feedback P<sub>3</sub> increased with errors, and decreased with learning. Other studies concerned with task difficulty and confirming versus disconfirming feedback reported similar results (Ritter et al., 1973; Squires et al., 1973-a). It is interesting to note that the reverse occurred with Feedback P<sub>4</sub>.

The scalp distribution of the various measurements will be considered only within the Experimental condition, unless theoretical clarification demands examination within other conditions.

For Baseline Offset, no significant cortical differences were registered, suggesting that when the post-imperative negativity did occur, it had a generally uniform scalp distribution, and that no one cortical area assumed the posited re-evaluation of performance. On the other hand, the lack of cortical differentiation may indicate that this negativity is not an index of re-evaluation, but a general arousal or preparation factor. The noted differences between selected populations (Timsit-Berthier, Delaunoy, Koninckx, & Rousseau, 1973) may merely reflect the subjective importance of the feedback and the necessity to prepare oneself for the next trial.

The Pre-slide CNV (see Table 17) revealed a significant electrode effect, { $F(5,50) = 3.41$ , conventional and conservative  $p < .01$ }, with CZ being significantly more negative than all other cortical areas.

Table 16

Means and Standard Deviations for Latencies Relating to Specific Late Components of the Evoked Potential, Measured from Onset of the Corresponding Stimulus, in the Experimental Condition at the CZ Cortical Scalp Electrode Site for Five States of Stimulus Sequence (labelled Preinsight, Insight, Confirm, Overlearn, and False Feedback)

Component		Slide P <sub>3</sub>	Slide P <sub>4</sub>	Feedback P <sub>3</sub>	Feedback N <sub>3</sub>	Feedback P <sub>4</sub>
Total	<u>M</u>	368.58	633.62	355.36	521.51	647.29
	<u>SD</u>	21.48	80.81	27.94	60.18	97.69
PINS	<u>M</u>	362.09	643.00	366.00	520.63	618.27
	<u>SD</u>	20.71	97.96	35.27	46.85	71.39
INS	<u>M</u>	369.45	643.27	353.41	489.27	636.54
	<u>SD</u>	19.06	85.30	21.95	40.44	99.81
CON	<u>M</u>	375.18	621.73	347.45	536.18	681.00
	<u>SD</u>	24.63	76.50	28.30	55.32	125.11
OVER	<u>M</u>	365.64	625.82	348.00	517.91	664.63
	<u>SD</u>	28.91	73.00	23.27	26.50	69.52
FFB	<u>M</u>	370.55	634.27	361.91	543.54	636.00
	<u>SD</u>	12.20	82.32	29.03	100.19	100.18

Table 17

Analysis of Variance of the Experimental  
Condition Pre-Slide CNV  
for Five Levels of Stimulus Sequence  
(labelled Preinsight, Insight, Confirm,  
Overlearn and False Feedback) at Six  
Cortical Scalp Electrode Sites:  
CZ, OZ, F3, F4, P3, P4

Source of Variation	<u>SS</u>	<u>df</u>	<u>MS</u>	<u>F</u>
B (Sequence)	.72	4	.18	.38
B x R (Replication) <sup>a</sup>	18.84	40	.47	
C (Electrode)	18.54	5	3.71	9.64* †
C x R	19.24	50	.38	
B x C	2.60	20	.13	.83
B x C x R	31.47	200	.16	
R	35.38	10	3.54	

<sup>a</sup>To facilitate comprehension, the corresponding error term is presented along with the appropriate source of variation.

Conventional  $F_{.99} (5,50) = 3.41$

\*Conventional  $p < .01$

Conservative  $F_{.95} (1,10) = 4.96$

†Conservative  $p < .05$

This confirms the central dominance of an attention CNV (Walter, 1967; Cohen, 1969). The relative equality of the other sites contradicts Poon et al. (1974), and Jarvilehto & Fruhstorfer (1970). It is, however, very difficult to compare across different tasks.

The Slide Slow Potential yielded significant differences between cortical areas {  $F(5,50) = 3.41$ , conventional and conservative  $p < .01$  }, with central and posterior areas being significantly more negative in relation to the frontal electrode sites (see Table 18, and Figure 15).

There seem to be four possible causes for this frontal positivity. One may be electro-oculogram effects. It is also feasible that the positive valence may reflect the other end of a negative (OZ) - positive dipole, although the large CZ negativity suggests this is not the case. It may also be that this is a frontal positivity truly associated with "thinking" and information processing. The fourth possibility may be the major factor, or may possibly interact with one or more of the above suggestions. This is the frontal positivity associated with the motor potential (Gilden et al., 1966).

The significant cortical differences with Pre-feedback CNV {  $F(5,50) = 3.41$ , conventional and conservative  $p < .01$  } show again that all posterior areas are significantly more negative than the two frontal electrode sites (see Table 19). The largest negativities were found at occipital and left parietal sites, a finding similar to the maximum PZ CNV found in a simpler pattern discrimination task (Poon et al., 1974).

Table 18

Analysis of Variance of the Experimental  
Condition Slide Slow Potential  
for Five Levels of Stimulus Sequence  
(labelled Preinsight, Insight, Confirm,  
Overlearn and False Feedback) at Six  
Cortical Scalp Electrode Sites:  
CZ, OZ, F3, F4, P3, P4

Source of Variation	<u>SS</u>	<u>df</u>	<u>MS</u>	<u>F</u>
B (Sequence)	17.48	4	4.37	11.44* †
B x R (Replication) <sup>a</sup>	15.29	40	.38	
C (Electrode)	268.88	5	53.78	27.34* †
C x R	98.35	50	1.97	
B x C	3.60	20	.18	1.85
B x C x R	19.36	200	.10	
R	20.40	10	2.04	

<sup>a</sup>To facilitate comprehension, the corresponding error term is presented along with the appropriate source of variation.

Conventional  $F_{.99} (4,40) = 3.83$   
Conventional  $F_{.99} (5,50) = 3.41$

\*Conventional  $p < .01$

Conservative  $F_{.99} (1,10) = 10.00$

†Conservative  $p < .01$



Figure 15

## Slide Slow Potential Scalp Distribution

The Slide Slow Potential examples across all six cortical scalp electrode sites are presented within the total sweep time as a visual aid in determining the scalp distribution. A prominent frontal negativity is noted for the Slide Slow Potential, measured as the average level of the waveform above baseline in the last 600 ms of the slide illumination.

The example was from an Experimental Overlearn trial, Subject K.B.

SLIDE SLOW POTENTIAL SCALP DISTRIBUTION

SUBJ: K·B

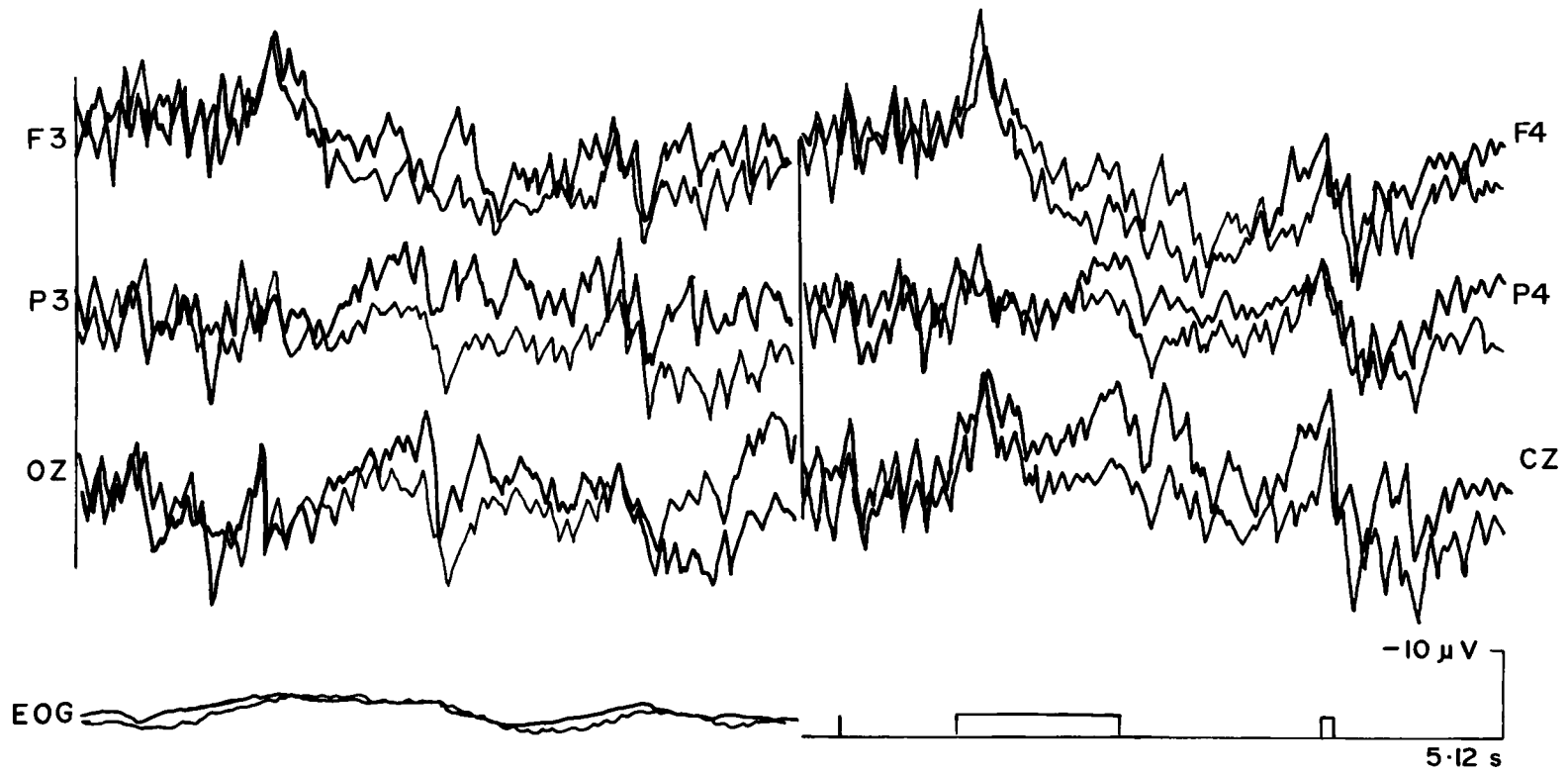


Table 19

Analysis of Variance of the Experimental  
Condition Pre-Feedback CNV  
for Five Levels of Stimulus Sequence  
(labelled Preinsight, Insight, Confirm,  
Overlearn and False Feedback) at Six  
Cortical Scalp Electrode Sites:  
CZ, OZ, F3, F4, P3, P4

Source of Variation	<u>SS</u>	<u>df</u>	<u>MS</u>	<u>F</u>
B (Sequence)	9.78	4	2.45	4.33*††
B x R (Replication) <sup>a</sup>	22.60	40	.56	
C (Electrode)	75.52	5	15.11	15.22*†
C x R	49.65	50	.99	
B x C	2.84	20	.14	1.34
B x C x R	21.19	200	.11	
R	39.50	10		

<sup>a</sup>To facilitate comprehension, the corresponding error term is presented along with the appropriate source of variation.

Conventional  $F_{.99} (4,40) = 3.83$   
Conventional  $F_{.99} (5,50) = 3.41$

\*Conventional  $p < .01$

Conservative  $F_{.99} (1,10) = 10.00$   
Conservative  $F_{.90} (1,10) = 3.29$

†Conservative  $p < .01$   
††Conservative  $p < .10$

The data suggests that this may represent a priming of the perceptual areas being used and/or an expectancy to feedback. Since the information was delivered visually, and probably analyzed in visual association areas, this occipital and parietal negativity may represent a preparation to receive feedback relevant to these association areas, even though the stimulus was auditory. A second possibility is that this indexes the preparation of the simultaneous processor located in the occipital-parietal area (Das et al., 1975). This concept dovetails with the more frontal-central CNV found in tasks that might be interpreted as demanding successive processing. Thus, the topographic distribution may depend on task requirements, as others had noted (Donchin et al., 1971; Rebert, 1972). Without a more precise analysis of the requirements and type of concomitant processing, this remains speculation.

Both suggestions are corroborated by an examination of the Pre-feedback CNV within the other two conditions. The same basic results occurred for Known Concept, while for Distraction, only OZ was significantly more negative than the frontal sites. This does seem to add evidence for the priming of a specific feedback-related cortical area.

There were no cortical differences at Slide P<sub>3</sub>. The results at Slide P<sub>4</sub> were similar to SSP. Since Slide P<sub>4</sub> probably reflected this SSP effect, it will not be discussed.

Because of the theoretical importance of  $N_1$ , and because the conventional and conservative  $F$  closely approximated the chosen level of significance {  $F(5,50) = 3.41$ , conventional  $p < .05$ , conservative  $p < .25$ }, it was decided to include the data and discuss the results as having possible relevance (see Tables 20A & 20B).

Within the Experimental condition, when the learning process is considered at each cortical electrode site, some interesting results are noted: CZ and P<sub>3</sub> have the largest amplitudes, generally being significantly larger than F<sub>3</sub>, OZ and P<sub>4</sub>. Within FFB alone, the parietal and occipital areas are significantly larger than the rest.

In general, it seems that  $N_1$  in the Experimental condition is more posterior than previously reported (Picton & Hillyard, 1974). In Known Concept, the  $N_1$  amplitude is more uniformly distributed, with CZ being significantly larger than all the other electrode areas. Finally, in the Distraction control,  $N_1$  is definitely and significantly a frontal-central phenomenon.

It may be that, in a relatively difficult concept task, the  $N_1$  becomes more specific to the sensory modality in which the information is being evaluated. The fact it was largest frontally in Distraction, and became more posterior in the Experimental task (especially with FFB), suggests that  $N_1$  may have both a non-specific diffuse function, and a specific function more related to specific stimulus meaning (Davis et al., 1972; Picton & Hillyard, 1974).

Table 20A

Analysis of Variance of the Experimental  
Condition Feedback  $N_1$  Amplitude  
for Five Levels of Stimulus Sequence  
(labelled Preinsight, Insight, Confirm,  
Overlearn and False Feedback) at Six  
Cortical Scalp Electrode Sites:  
CZ, OZ, F3, F4, P3, P4

Source of Variation	<u>SS</u>	<u>df</u>	<u>MS</u>	<u>F</u>
B (Sequence)	27.29	4	6.82	6.96*†
B x R (Replication) <sup>a</sup>	39.19	40	.98	
C (Electrode)	16.65	5	3.33	3.01
C x R	55.32	50	1.11	
B x C <sup>b</sup>	7.98	20	.40	3.07*††
B x C x R	26.01	200	.13	
R	42.40	10	4.24	

<sup>a</sup>To facilitate comprehension, the corresponding error term is presented along with the appropriate source of variation.

<sup>b</sup>Analysis of variance results for simple main effects for Feedback  $N_1$  Amplitude are presented in Table 20B.

Conventional  $F_{.99}$  (4,40) = 3.83                      \*Conventional  $p < .01$   
 Conventional  $F_{.95}$  (5,50) = 3.41  
 Conventional  $F_{.99}$  (20,200) = 1.97

Conservative  $F_{.95}$  (1,10) = 4.96                      †Conservative  $p < .05$   
 Conservative  $F_{.75}$  (1,10) = 1.49                      ††Conservative  $p < .25$   
 Conservative  $F_{.90}$  (1,10) = 3.29

Table 20B

Analysis of Variance for Simple Main Effects  
Referring to Significant Interaction in Table 20A

Source of Variation	<u>SS</u>	<u>df</u>	<u>MS</u>	<u>F</u>
B at C				
B at c <sub>1</sub> (CZ)	13.54	4	3.38	12.46*
B at c <sub>2</sub> (OZ)	1.33	4	.33	1.23
B at c <sub>3</sub> (F3)	8.55	4	2.14	7.87*
B at c <sub>4</sub> (F4)	4.14	4	1.03	3.81*
B at c <sub>5</sub> (P3)	3.22	4	.80	2.96*
B at c <sub>6</sub> (P4)	4.43	4	1.11	4.08*
Pooled error			.27	
C at B				
C at b <sub>1</sub> (PINS)	1.61	5	.32	.99
C at b <sub>2</sub> (INS)	6.05	5	1.21	3.71*
C at b <sub>3</sub> (CON)	6.71	5	1.34	4.12*
C at b <sub>4</sub> (OVER)	4.26	5	.85	2.61*
C at b <sub>5</sub> (FFB)	6.00	5	1.20	3.68*
Pooled error			.33	

NOTE. See page 88 of text for explanation of derivation of error term and F significance.

\*p < .05

It does then seem to reflect a higher order analysis rather than differential recognition of signals.  $N_1$  analyzes information according to the mode in which the analysis will be most meaningful.

The more posterior Pre-feedback CNV also implies that its function may be integrated with  $N_1$ . It is difficult with the present analysis to tell whether they are independent phenomena, or to what degree the  $N_1$  may be a mere reflection of this Pre-feedback CNV.

Significant cortical area-learning process interaction was achieved with the  $P_3$  component to feedback,  $F(20,200) = 4.67$ , conventional  $p < .01$ , conservative  $p < .10$  (see Tables 21A & 21B). No significant interaction effects were noted for the two control conditions. Within each cortical area, FFB was significantly larger than most other learning stages, with CON and OVER being smallest. At CZ, F3, P4 and P3 cortical locations, PINS and INS were also significantly larger than CON and/or OVER. Within F4, the only significant difference was FFB greater than OVER. One apparently definite conclusion is that the right frontal cortex is little connected with concept learning.

When the cortical areas were considered at each stage of learning, the following results were noted (see Figure 16). For all levels of learning, CZ was significantly larger than all other cortical areas, except at OVER, when it was not different significantly from F3, and at CON, where significant difference lacked with P4. This reaffirms the  $P_3$  central dominance, for all levels of concept learning, suggesting

Table 21A

Analysis of Variance of the Experimental  
Condition Feedback P3 Amplitude  
for Five Levels of Stimulus Sequence  
(labelled Preinsight, Insight, Confirm,  
Overlearn and False Feedback) at Six  
Cortical Scalp Electrode Sites:  
CZ, OZ, F3, F4, P3, P4

Source of Variation	<u>SS</u>	<u>df</u>	<u>MS</u>	<u>F</u>
B (Sequence)	98.23	4	24.56	14.50*†
B x R (Replication) <sup>a</sup>	67.74	40	1.69	
C (Electrode)	86.94	5	17.39	16.73*†
C x R	51.96	50	1.40	
B x C <sup>b</sup>	17.20	20	.86	4.67*††
B x C x R	36.81	200	.18	
R	142.49	10	14.25	

<sup>a</sup>To facilitate comprehension, the corresponding error term is presented along with the appropriate source of variation.

<sup>b</sup>Analysis of variance results for simple main effects for Feedback P300 Amplitude are presented in Table 21B.

Conventional  $F_{.99} (4,40) = 3.83$       \*Conventional  $p < .01$   
 Conventional  $F_{.99} (5,50) = 3.41$   
 Conventional  $F_{.99} (20,200) = 1.97$

Conservative  $F_{.99} (1,10) = 10.00$       †Conservative  $p < .01$   
 Conservative  $F_{.90} (1,10) = 3.29$       ††Conservative  $p < .10$

Table 21B

Analysis of Variance for Simple Main Effects  
Referring to Significant Interaction in Table 21 A

Source of Variation	<u>SS</u>	<u>df</u>	<u>MS</u>	<u>F</u>
B at C				
B at c <sub>1</sub> (CZ)	43.74	4	10.94	25.33*
B at c <sub>2</sub> (OZ)	11.56	4	2.89	6.70*
B at c <sub>3</sub> (F3)	17.55	4	4.39	10.16*
B at c <sub>4</sub> (F4)	3.23	4	.81	1.87*
B at c <sub>5</sub> (P3)	18.92	4	4.73	10.96*
B at c <sub>6</sub> (P4)	20.71	4	5.18	11.99*
Pooled error			.43	
C at B				
C at b <sub>1</sub> (PINS)	27.40	5	5.48	15.57*
C at b <sub>2</sub> (INS)	19.48	5	3.90	11.07*
C at b <sub>3</sub> (CON)	8.69	5	1.74	4.94*
C at b <sub>4</sub> (OVER)	7.24	5	1.45	4.11*
C at b <sub>5</sub> (FFB)	41.09	5	8.22	23.35*
Pooled error			.35	

NOTE. See page 88 of text for explanation of derivation of error term and F significance.

\*p < .05

Figure 16Feedback P<sub>3</sub> Scalp Distribution x Sequence

Feedback P<sub>3</sub> baseline to peak measurements in microvolts are presented for the six cortical scalp electrode sites across the learning process within the Experimental condition.

### P<sub>3</sub> SCALP DISTRIBUTION x SEQUENCE

#### PREINSIGHT

10.46	7.55	8.06	6.48
15.23			14.21
8.61	9.95	8.98	10.37
5.65			7.55

#### INSIGHT

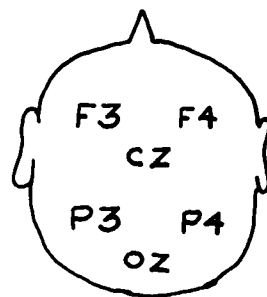
#### CONFIRM

5.19	6.25
8.66	
5.09	6.44
3.10	

#### OVERLEARN

6.71	5.60	12.50	8.80
8.94			19.63
5.32	5.70	12.41	13.75
4.47			9.22

#### FALSE FB



that this is a grand average. It is also noted that OZ had the smallest P<sub>3</sub> wave magnitude, suggesting that the P<sub>3</sub> was not connected with the specific area related to the type of information (visual) being evaluated.

Another general comment is that the second largest magnitude after CZ was the right parietal cortical location, for all levels of learning except PINS and OVER, in which F3 had the second largest P<sub>3</sub> wave. There is a general tendency, then, for P<sub>3</sub> to feedback in a concept learning task to be maximal, after CZ, at P4 and F3.

A closer inspection at each learning level points to a possible shift in cortical P<sub>3</sub> magnitude as an individual learns. This inspection will consider all magnitudes except CZ.

With FFB, P4, F3 and P3 were almost of equal magnitude, all being significantly larger than OZ and F4. In PINS, there appeared to be a frontal shift. F3, P4 and P3 were all significantly larger than OZ, and in addition, F3 was significantly larger than P3, and P4 > F4. With the achievement of insight, P<sub>3</sub> became more parietal, with P4 and P3 being significantly larger than F4, and the former also significantly more positive than OZ, although P3 was not significantly different from F3. With CON, the right hemisphere became larger, with P4 and F4 significantly larger than OZ. With OVER, F3 was significantly larger than OZ.

These results tentatively suggest that, with the first shock of concept change in this task, all cortical areas have enhanced P<sub>3</sub> amplitudes, with P4, F3 and P3 all assuming an equal role. False feedback

was not expected to engender learning; this  $P_3$  may be an evaluation of the feedback in the direction of a general need to change hypotheses. With Preinsight, where hypotheses are being tested,  $P_3$  is maximal (again, after CZ) left frontally. Once the criterion is learned, feedback evaluation registers more parietally. These results appear to corroborate the proposal of amount of information and level of difficulty as being a relevant factor in  $P_3$  topography (Courchesne et al., 1975).

It may be that both these and Courchesne et al.'s (1975) results are explainable by Nauta's (1972) concept of the linear cortico-cortical organization of the cortex, in which there are hierarchies of information processing. Since the frontal cortex is mainly involved in planning behavior, it is expected that it would be involved in some fashion only in hypothesis and strategy evaluation, and therefore mainly in PINS. The large  $P_3$  at the left frontal site in OVER may reflect the subject's anticipation and preparation for concept change, as they often reported they did. These considerations are also meaningful in Das et al.'s (1975) model.

For the  $N_3$  component to feedback, significant interaction results were observed,  $F(20,200) = 4.13$ , conventional  $p < .01$ , conservative  $p < .10$  (see Tables 22A & 22B). Considering each cortical electrode site, the general observation was that FFB, PINS and INS were less negative than CON and OVER, with FFB exhibiting the least negativity. These results suggest that, to some degree at least, Feedback  $N_3$  is affected by the  $P_4$  positive waveform.

Table 22A

Analysis of Variance of the Experimental  
Condition Feedback N<sub>3</sub> Amplitude  
for Five Levels of Stimulus Sequence  
(labelled Preinsight, Insight, Confirm,  
Overlearn and False Feedback) at Six  
Cortical Scalp Electrode Sites:  
CZ, OZ, F3, F4, P3, P4

Source of Variation	<u>SS</u>	<u>df</u>	<u>MS</u>	<u>F</u>
B (Sequence)	76.98	4	19.25	10.49*†
B x R (Replication) <sup>a</sup>	73.41	40	1.84	
C (Electrode)	35.08	5	7.02	10.24*†
C x R	34.27	50	.69	
B x C <sup>b</sup>	13.97	20	.70	4.13*††
B x C x R	33.81	200	.17	
R	59.82	10	5.98	

<sup>a</sup>To facilitate comprehension, the corresponding error term is presented along with the appropriate source of variation.

<sup>b</sup>Analysis of variance results for simple main effects for Feedback N<sub>3</sub> Amplitude are presented in Table 22B.

Conventional $F_{.99}$ (4,40) = 3.83	*Conventional $p < .01$
Conventional $F_{.99}$ (5,50) = 3.41	
Conventional $F_{.99}$ (20,200) = 1.97	
Conservative $F_{.99}$ (1,10) = 10.00	†Conservative $p < .01$
Conservative $F_{.90}$ (1,10) = 3.29	††Conservative $p < .10$

Table 22B

Analysis of Variance for Simple Main Effects  
Referring to Significant Interaction in Table 22 A

Source of Variation	<u>SS</u>	<u>df</u>	<u>MS</u>	<u>F</u>
B at C				
B at c <sub>1</sub> (CZ)	25.78	4	6.44	14.37*
B at c <sub>2</sub> (OZ)	14.73	4	3.68	8.21*
B at c <sub>3</sub> (F3)	9.66	4	2.41	5.38*
B at c <sub>4</sub> (F4)	1.88	4	.47	1.05
B at c <sub>5</sub> (P3)	19.37	4	4.84	10.80*
B at c <sub>6</sub> (P4)	19.52	4	4.89	10.91*
Pooled error			.45	
C at B				
C at b <sub>1</sub> (PINS)	8.73	5	1.75	6.37*
C at b <sub>2</sub> (INS)	14.60	5	2.92	10.66*
C at b <sub>3</sub> (CON)	.86	5	.17	.63
C at b <sub>4</sub> (OVER)	2.49	5	.50	1.82*
C at b <sub>5</sub> (FFB)	22.46	5	4.49	16.39*
Pooled error			.27	

NOTE. See page 88 of text for explanation of derivation of error term and F significance.

\*p < .05

For PINS, INs and FFB, there was a significant difference in the direction of increased negativity for F4 and F3 over the other cortical areas. For OVER, F4 and F3 were significantly more negative than P4 alone. In addition, with FFB, F4 was significantly more negative than F3. It appears that the N<sub>3</sub> component is a negative frontal phenomenon.

No significant interaction effects were noted for P<sub>4</sub> to feedback (see Table 23). There was, however, a significant cortical effect, {  $F(5,50) = 8.48$ , conventional  $p < .01$ , conservative  $p < .05$  }, with CZ, P4 and OZ being significantly more positive than F4 and F3, and P3 significantly greater than F4. This is illustrated in Figures 17, 18 and 19. P<sub>4</sub> is, then, a specific posterior, parieto-occipital, phenomenon in this specific paradigm. There were no P<sub>4</sub> differences in the two control conditions. The lack of the significant P<sub>4</sub> interaction effect that was noted with N<sub>3</sub> suggests some independence of these components.

Table 23

Analysis of Variance of the Experimental  
Condition Feedback P<sub>4</sub> Amplitude  
for Five Levels of Stimulus Sequence  
(labelled Preinsight, Insight, Confirm,  
Overlearn and False Feedback) at Six  
Cortical Scalp Electrode Sites:  
CZ, OZ, F3, F4, P3, P4

Source of Variation	<u>SS</u>	<u>df</u>	<u>MS</u>	<u>F</u>
B (Sequence)	49.00	4	12.25	7.45*†
B x R (Replication) <sup>a</sup>	65.76	40	1.64	
C (Electrode)	26.22	5	5.24	8.48*†
C x R	30.92	50	.62	
B x C	6.80	20	.34	1.99*
B x C x R	34.23	200	.17	
R	116.78	10	11.68	

<sup>a</sup>To facilitate comprehension, the corresponding error term is presented along with the appropriate source of variation.

Conventional  $F_{.99}$  (4,40) = 3.83  
 Conventional  $F_{.99}$  (5,50) = 3.41  
 Conventional  $F_{.99}$  (20,200) = 1.97

\*Conventional  $p < .01$

Conservative  $F_{.95}$  (1,10) = 4.96

†Conservative  $p < .05$



Figure 17

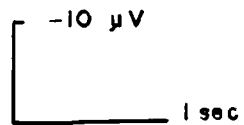
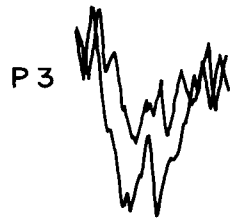
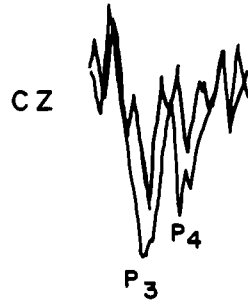
## Feedback Response Example 1

Feedback response to the 4000 HZ toneburst signifying an incorrect response in Preinsight trials reveals the enhanced P3 (mean latency = 355 ms) and P4 (mean latency = 647 ms) positive waves associated with learning in this task. The scalp distributions of the two components were distinct, the P4 being of greater amplitude in the parieto-occipital regions. Subject = K.B.

FEEDBACK RESPONSE

PREINSIGHT TRIALS

EOG 



SUBJ: K·B·

Figure 18

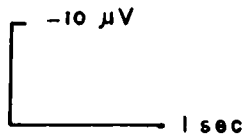
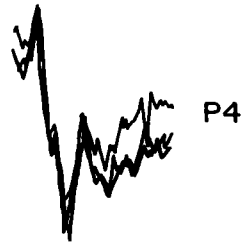
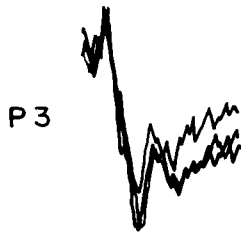
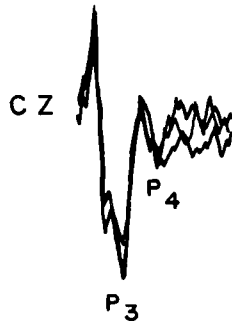
## Feedback Response - Example 2

Feedback results similar to Figure 13 are noted to 1000 HZtonebursts in Insight trials. The difference in scalp distribution between the late positive P<sub>3</sub> and P<sub>4</sub> waves is more prominent. Subject = G.S.

FEEDBACK RESPONSE

INSIGHT TRIALS

EOG 



SUBJ: G·S·

Figure 19

Feedback P<sub>4</sub> Scalp Distribution x Sequence

Feedback P<sub>4</sub> baseline to peak measurements in microvolts are presented for the six cortical scalp electrode sites across the learning process within the Experimental condition.

# P<sub>4</sub> SCALP DISTRIBUTION x SEQUENCE

## PREINSIGHT

3.24	1.89	1.02	.69
5.60		4.63	
5.00	4.77	4.03	4.31
5.56		4.72	

## INSIGHT

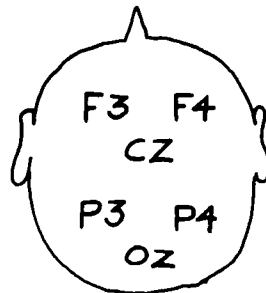
## CONFIRM

1.16	1.11
	3.01
1.81	2.32
	1.90

## OVERLEARN

1.11	1.06	5.65	2.50
2.96		8.80	
2.45	3.10	7.55	8.75
2.87		7.87	

## FALSE FB



## CHAPTER IV

### Discussion

This experimental study of the electrophysiological correlates of human concept learning has shown that there are evoked potential components that do vary with the learning process as established by this experimental design.

Pre-slide CNV, the preparation to receive information, represents an attentional effect seen only when task-relevant data is presented, as in the Experimental and Known Concept conditions. The Slide Slow Potential, representing the electrophysiological changes during exposure of the visual information, is composed of possibly three aspects: the sensory slow potential, which is constant for all conditions; the actual information processing; and the motor readiness potential. As expected, the Experimental and Known Concept conditions were significantly larger than the Distraction control. Processing should be occurring in both former conditions, and these two conditions demand a motor response.

A design eliminating the movement artifact is required. However, the possibility the Slide Slow Potential represents information processing is underlined by its reciprocal relationship with Feedback P<sub>3</sub>. As a concept is learned, SSP increases while P<sub>3</sub> decreases. An anxiety ceiling effect concomitant with errors may be influencing this slow shift.

Pre-feedback CNV also seems to be some type of attention-preparatory effect. Its large parieto-occipital effect suggests that

this is a relatively specific cortical arousal or preparatory state, specific to the mode in which the relevant information was presented (visual), and according to which the feedback should be evaluated. The topographical similarity with Poon et al. (1974) also suggests that this cortical organization may be typical of a specific mode of processing information in a pattern or concept learning task, perhaps indexing the simultaneous processing hypothesized to occur in the parieto-occipital region (Das et al., 1975).

Feedback  $N_1$  was posterior-dominant, maximal at P3 and OZ with change of concept, indicating that its role is specific to the mode of relevant information, perhaps in the sense of stimulus set. It will be necessary to show  $N_1$  -- Pre-feedback CNV independence before postulating more specific proposals.

The most important results were observed in the late positive components after feedback. Feedback  $P_3$  increased with the specific learning stages of Preinsight, Insight and False Feedback. This appears to reflect the appreciation of feedback information, as if the results of proposed hypotheses were being evaluated, perhaps to some type of cognitive template. It also may be a sign of information load, which may well vary with feedback evaluation. The topography change from central-frontal for Preinsight to central-parietal may index the level of difficulty of cortical processing, in the sense of planning new hypotheses being frontally situated while confirmation of correct attempts being a more parietal phenomenon. The observation of a large  $P_3$  to Insight hints that the difference in learning may not be only on the dimension of correct versus error (Levine, 1966).

A relatively new evoked potential phenomenon appeared in relation to feedback stimuli. This definite late positive wave occurring with a mean latency of 647 ms, was termed "P<sub>4</sub>" to distinguish it from the earlier P<sub>3</sub> wave (355 ms). The P<sub>4</sub>, similar to the P<sub>3</sub>, was larger in the Preinsight, Insight and False Feedback trials, especially when the subject was having difficulty with the task. In addition in being a later component than the P<sub>3</sub>, it had a distinctly different scalp distribution, being of greater amplitude in the parieto-occipital regions.

It appears the P<sub>4</sub> may reflect the utilization of feedback evaluation (P<sub>3</sub>) in concept learning. Certain other considerations led to the possibility of the P<sub>4</sub> being a true learning wave, perhaps a "learning to learn" wave. It decreased in size and generally disappeared when the concept was achieved. The P<sub>3</sub>, however, persisted, although smaller. If the subject was very familiar with the task, he had no evoked P<sub>4</sub>. When unfamiliar (as in the pilot study), or when unable to learn the correct sorting criterion, the Feedback P<sub>4</sub> was evident. The posterior P<sub>4</sub> may reflect a resetting of a primary sensory area.

The inherent difficulties in examining learning in humans led to the necessity of training the subjects in the task, and in eye control etc. It now seems necessary to not train individuals. This may be accomplished by averaging only the feedback response, and being less specific in time-locking other aspects. Tasks could be given in the auditory modality, thereby decreasing contamination from eye movements.

Such procedures would also increase the possible practical applications of the electrophysiological correlates of learning. The stringent methodology used in this study would be impossible to use with children, for example, or if it was desired to study learning disabilities.

This research was not the first to notice such a wave; it does seem to be the first to describe psychological processes correlated with its variation in amplitude. The P<sub>4</sub> appears to be a sharper, more definite, positive waveform than the Slow Wave described by Squires, N. et al. (1975). It had been reported as an accidental finding (Cael et al., 1974), or statistically analyzed without noting its significance or relationship to psychological events (Karlin et al., 1971). Jenness (1972), who had noted it in a simple pitch discrimination learning experiment, suggested that it may be specific to that task.

It was wondered why previous feedback studies, even using similar stimuli, did not result in a late positive P<sub>4</sub> (Picton et al., in press-b). The difference may lie in the type and complexity of task. Concept learning may yield more complex and different electrophysiological correlates than the simpler perception tasks used in most P<sub>3</sub> research. It may also require a longer sweep time and longer time constant to see the wave. Finally, since P<sub>4</sub> was maximal at OZ, which is not a commonly used electrode site, this component may have not been obvious.

There is not sufficient evidence to conclude that the scalp distribution results reflect the cortico-cortical organization of the brain proposed by Nauta (1972). The shift of the Feedback P<sub>3</sub>, the

possible parietal P<sub>3</sub> - frontal N<sub>3</sub> - parieto-occipital P<sub>4</sub> complex with learning very tentatively suggests that the concept of flow of information following Nautian lines may exist, and is a viable area for future research.

It was strongly felt after statistical analysis of the data and visual examination of the results that the true relationship of evoked potentials with concept learning is much more prominent and constant than was being revealed even by the highly significant results of this dissertation. Several logical reasonings supported this observation.

It had originally been thought that the complexity of the paradigm would obviate experimenter-task bias. It was soon observed that the highly involved and experienced subjects were most affected by the repeated measures design and carry-over effect. The feedback signals in the control conditions had somehow become imbued with a meaning similar to the Experimental condition, resulting in some degree of loss of the purpose of the control. This result was not surprising, since the late components of the evoked potential studied in this research were chosen for their sensitivity to subjective psychological influences.

The reality of carry-over effect is supported by the fact that evoked potentials may reflect more than what the stimuli are presenting. The lack of a stimulus can evoke a response (Klinke et al., 1968; Sutton et al., 1967; Weinberg et al., 1970). Content expectation can actually change the evoked potential results in the direction of the expectation (Begleiter et al., 1973; Buchsbaum et al., 1974). Finally,

it has been shown that conditioning of evoked potentials can occur (Lelord, 1973). It seems very likely, then, that there was a carry-over conditioning effect, and that the results within the Experimental condition are indeed reflective of the learning process. Replication with random groups is a necessary follow-up. There must be no room for "subject option" (Sutton, 1969).

In order to avoid the risk of averaging across different perceptual states and losing relevant sources of variance (Sutton, 1969), it is important to isolate subjective psychological reactions. One means to do this would be to obtain ratings on each trial to scale the level of certainty (Squires, K. et al., 1975; Sutton, 1969). It may also be necessary to obtain a more discrete subjective evaluation. Subjects could be asked after each trial what mode of processing they used. Those with a common approach could be averaged together. Perhaps by this means the various cognitive strategies noted in the concept learning review could be analyzed and correlated with electrophysiological components. Trial by trial observations of evoked potential averages during actual recording suggested that the averaging process was eliminating some possibly interesting results.

The subjective comments of subjects indicated a need to control when thinking and possibly learning was occurring. Some subjects made hypotheses between trials, and processed the slide information merely in an information sorting manner. Others made hypotheses during the slide illumination. At various times, certain subjects anticipated criterion change in Overlearn, so that they rarely made Preinsight errors.

Personality may well be a very important variable in the relationship of learning and evoked potentials. Authors have already suggested that there may be basic physiological differences between types of people, affecting some or all modes of behavior (Eysenck, 1971; Pribram, 1968). Poon et al.'s (1974) use of a personality measurement showed that the P<sub>3</sub> did vary as a function of the cortical area, the level of learning, and an attitudinal dimension as measured by Rotter's internal-external locus of control scale.

Using the same design as this thesis, it may be possible to obtain more meaningful data by using different kinds of measurements, such as waveform morphology (Weinberg, 1975).

A necessary dimension is the independence of the components associated with learning. Multivariate Anovas would be suitable, if available, or perhaps a covariate analysis (Huck & McLean, 1975). Evoked potential research has recently suggested the use of both factor analysis, and stepwise discriminant function analysis (Donchin & Herning, 1973; Donchin et al., 1973). Their use at the present time seemed conceptually desirable, but not opportune for the small subject population (Nunnally, 1967, p. 291). Moreover, stepwise discriminant function analysis has been reported to exaggerate the extent of differences (Lachin & Schachter, 1974).

The study points to possibilities for future research. It seems relevant to average the data according to the different concepts: color, mathematical operations, etc. The results of this may shed some light on the surprisingly large magnitude of cortical electrode site P4.

It is hoped that future clinical applications may be forthcoming, such as the diagnosis of learning disabilities and functional disorders. This would require the correlation of specific waveforms with specific processes, and the establishment of norms.

Diagnosis should lead to rehabilitation. It may be possible to test the Vygotsky-Luria concept of the development of thought through language (Stuss, 1975) to see if language can be used as an instrument to teach individuals how to learn and think. Some pioneering work suggests that this indeed may be possible (Klorman, 1974; Walter, 1973).

In conclusion, it has been shown that there do exist electrophysiological correlates of human concept learning. It seems that there may even exist a particular waveform, termed the  $P_4$ , that is a true learning wave, and that, along with  $P_3$ , forms a complex related to the evaluation and utilization of feedback information.

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APPENDIX 1

WRITTEN INSTRUCTIONS GIVEN  
FOR THE PILOT STUDY

INSTRUCTIONS FOR PILOT STUDY

Approximately 500 slides will be shown. Each slide contains and varies on all of the following four dimensions: colour, shape (form), number of shapes, and written number. Specifically, each of the four dimensions has four possible variations. A slide may have one of the following four shapes: circle, square, triangle, or cross. The number of these shapes may vary from one to four. In addition, the colour of the shape(s) may be red, blue, green, or orange. Finally, in the centre of each slide, there is a written number, from one to four.

For example, one slide may indicate three yellow crosses, with the written number two; the next- four blue triangles, with the written number four; then- one blue triangle, with the written number three, etc.

A fifth dimension is mathematical operations: this is the absolute difference between the number of shapes and the written number. There are therefore five different possible concepts in the slides: colour, form, the number of forms, written number, and mathematical operations. In other words, the information present in the slides may be sorted five possible different ways.

In front of you are four buttons, one for each finger of the right hand, the buttons being numbered from 1-4, beginning with the index finger. Each button corresponds to one of the possible variations of the concepts, as in the schema below,

CONCEPT	BUTTON			
	1	2	3	4
colour	red	blue	green	orange
form	circle	square	triangle	cross
number of forms	1	2	3	4
written number	4	3	2	1
math. operations	0	1	2	3

The slides have already been subdivided according to groups based on the five different concepts. An average of twenty slides grouped according to one concept constitutes one of these preset subdivisions, the range being from 18-23. There are five different groupings of each of the concepts, with one of them having a sixth. The total number of groups is thus 26.

The general aim of the task is to find out how the slides have been subdivided. The best approach is to establish hypotheses as to how the slides have been grouped; this hypothesis is tested by matching the button with the slide. Thus, if color is the hypothesis, the object is to press the button which matches the color shown on the slide. Feedback is given which can be used to modify and make new hypotheses, or to confirm the hypothesis tested. Pressing the button which stands for the correct answer will give a low tone, indicating a correct response. A high tone means an incorrect response.

After approximately 20 slides, the concept will change without any warning, and the process must be repeated. The obvious stipulation is that the same concept grouping will not be back to back.

There is a specific procedure in the way each slide will be presented. First, you will hear a warning click, indicating that in .8 seconds, a slide will be presented for 1.2 seconds. You must press whatever button you have chosen as quickly as possible after the slide goes off. There is a time limit of 1 sec. after the slide goes off in which your response has any value. Feedback will be presented in the manner already described (i.e., low tone = correct; high tone = incorrect), 1.5 sec. after the slide goes off. If you did not press a button, or accidentally pressed a button before or after the one sec. response contingency time, no feedback will be given. It is important for the experiment that this occur not at all if possible.

The next instructions are very important for the success of the experiment. In general, you must sit quietly in this chair with your head resting against the headrest. Look at the middle of the screen and do not blink during the time of the trial. The best procedure is to blink three to four seconds AFTER the feedback has been given, and then to fixate and wait for the next trial. Inter-trial intervals will be from 5-15 seconds. The practice trials will soon give you a rhythm of blinking and not blinking that is not very difficult. Finally, it is necessary to keep your tongue away from the upper roof of your mouth, and to eliminate any movement, even frowning of the brow. You will be informed when there is a break and you can stretch and move.

A second aspect of the experiment is very similar to the first. This time you do not have to find out the concept. The only requirements are to sit quietly, not blink, and push any button at all as soon as the slide goes off. You will hear tones as if indicating the response is correct or not. However, the feedback has no necessary relevance to the response. Rather, feedback will come in a sequence of 18-23 slides, similar to the pattern you would get if you were involved in the test. For example, the first 2-6 slides may be given incorrect feedback, the rest with correct. After a set number of slides, this basic pattern will repeat itself. One important reminder: even though you have no active mental part to play, please try to be attentive.

APPENDIX 2

WRITTEN INSTRUCTIONS FOR  
THE EXPERIMENTAL STUDY

### INSTRUCTIONS FOR EXPERIMENTAL STUDY

This experiment consists of three parts. One of these is similar to that which has already been explained to you. The task requires you to try to sort the slides which are presented according to one of the five possible concepts, using the feedback you receive via the tones to help you change your hypotheses. The one difference is that the same concept will hold for an average of only 10 slides (range 9-12), after which the concept underlying the slide will change. Again, the only stipulation in the order of the concepts is that the same concept will not be presented twice in a row.

A second aspect is as follows. The slide will be presented in the regular manner, and you are requested to look at them as usual. However, you will have nothing to do with the slide. You do not have to figure out the concept, or press a button, even though you will receive feedback as if you were doing so.

The task you have to perform during this time is this. Starting with the number 10,000, subtract 1. From this number (9,999), subtract 2, and from that result, subtract 3, and the next time 4, etc. Continue to do so, until you have subtracted the number 20. You must remember this sum and report it after this part is completed. Using that result, begin the procedure again, subtracting 1, then 2, then 3. When you have again subtracted 20, remember this number. DO NOT SUBVOCALIZE, OR MOVE.

In the third part, you will be informed each time there is a new concept. Using this information, you must respond as in the first part. You therefore should get all correct responses. At random times, however, I will give you false feedback; i.e., you will be given feedback that the response is incorrect, even though it was correct. The incorrect feedback does not signify a concept change. I will inform you each time the concept does change, so that you will always be aware of the required correct response. Therefore you should completely ignore the feedback stimuli.

APPENDIX 3

POST EXPERIMENT QUESTIONNAIRE

POST EXPERIMENT QUESTIONNAIRE

This questionnaire is designed to tap various experiences you had during the experiment.

- A. Please circle one number for each section which best matches the level of your experience. Do not circle the middle number unless absolutely necessary. Notice that the numbers may have two nuances, depending on the meaning of the question.

	least 1 not at all	2	3 average	4	5 extremely most			
			<u>ANXIETY</u>			<u>MOTIVATION</u>		<u>ATTENTION</u>
1. Errors before finding correct concept.			1 2 3 4 5			5 4 3 2 1		1 2 3 4 5
2. First experiences at finding correct concept.			5 4 3 2 1			1 2 3 4 5		5 4 3 2 1
3. Confirmation of discovery.			1 2 3 4 5			5 4 3 2 1		1 2 3 4 5
4. "Overlearning".			5 4 3 2 1			1 2 3 4 5		5 4 3 2 1
5. Anticipation of the change of concept.			1 2 3 4 5			5 4 3 2 1		1 2 3 4 5
6. Actual change of concept.			5 4 3 2 1			1 2 3 4 5		5 4 3 2 1

- B. Describe in a few words your experiences and attitudes etc. about the following.

1. Being wrong before finding the correct concept.

2. Achieving the correct concept: was it an "AHA" experience? Did it take more than one correct answer for it to register?
  
3. What happened when your original insight was confirmed?
  
4. Describe the experience of "overlearning".
  
5. How did you react when the concept changed?

APPENDIX 4

MEANS AND STANDARD DEVIATIONS ACCORDING TO  
STIMULUS SEQUENCE, CONDITION, AND  
CORTICAL SCALP LOCATION FOR  
ALL DEPENDENT MEASURES

Variables	Total	CZ	OZ	F3	F4	P3	P4	
<u>Pre-Slide CNV</u>								
Experimental								
PINS	M	- 2.46	- 4.63	- 1.88	- 2.09	- 1.55	- 2.63	- 1.96
	<u>SD</u>	2.24	2.07	2.13	2.47	1.83	2.12	1.69
INS	M	- 2.44	- 4.52	- 1.32	- 1.51	- 0.87	- 4.50	- 1.94
	<u>SD</u>	3.92	1.64	1.69	1.66	2.61	8.31	0.94
CON	M	- 2.72	- 4.71	- 1.46	- 3.05	- 1.92	- 2.73	- 2.44
	<u>SD</u>	2.17	2.79	1.68	2.18	1.87	1.80	1.28
OVER	M	- 2.62	- 4.88	- 1.55	- 2.32	- 2.02	- 2.58	- 2.39
	<u>SD</u>	2.87	3.19	1.99	3.03	3.44	2.59	2.04
FFB	M	- 2.08	- 4.54	- 1.41	- 1.36	- 1.05	- 2.48	- 1.67
	<u>SD</u>	2.86	2.31	3.59	2.69	2.94	2.52	1.85
Known Concept								
PINS	M	- 2.02	- 4.71	0.47	- 2.88	- 1.97	- 2.04	- 0.98
	<u>SD</u>	2.98	2.36	3.68	2.65	2.81	1.63	2.10
INS	M	- 2.46	- 4.92	- 0.53	- 2.77	- 2.19	- 2.45	- 1.87
	<u>SD</u>	2.97	3.35	2.28	3.20	2.76	2.92	1.82
CON	M	- 1.64	- 3.62	- 0.38	- 1.68	- 0.69	- 2.28	1.17
	<u>SD</u>	2.70	2.93	2.57	3.13	2.05	2.15	2.45
OVER	M	- 2.37	- 4.79	- 0.48	- 2.38	- 1.76	- 2.77	- 2.01
	<u>SD</u>	2.95	3.38	2.36	2.36	2.77	2.98	2.51
FFB	M	- 1.70	4.65	0.32	- 0.98	- 1.25	- 2.18	- 1.50
	<u>SD</u>	4.27	4.71	3.72	3.60	5.57	3.05	3.79
Distraction								
PINS	M	- 0.57	- 1.11	- 0.66	- 1.24	- 0.47	- 0.33	0.40
	<u>SD</u>	2.78	2.54	4.05	2.93	2.52	2.26	2.29
INS	M	- 0.26	- 1.18	1.19	- 1.46	- 0.58	0.24	0.21
	<u>SD</u>	2.73	2.99	1.89	3.65	3.35	1.64	1.75
CON	M	- 0.53	- 1.95	1.23	- 1.15	- 1.33	- 0.58	0.60
	<u>SD</u>	2.32	1.71	2.92	1.99	1.42	2.31	2.00
OVER	M	- 0.32	- 0.63	1.24	- 1.43	- 1.11	0.45	0.45
	<u>SD</u>	2.38	2.70	2.70	1.82	2.31	1.82	2.19
FFB	M	- 1.01	- 0.91	- 0.19	- 2.06	- 1.36	- 0.56	- 0.97
	<u>SD</u>	2.55	3.44	2.06	2.94	2.35	2.58	1.69

NOTE. All measurements are amplitudes measured in microvolts, excepting designated latencies, measured in milliseconds.

Variables	Total	CZ	OZ	F3	F4	P3	P4	
<u>Slide P3 Amplitude</u>								
Experimental								
PINS	M	2.50	0.63	0.41	3.71	6.07	1.22	2.98
	<u>SD</u>	5.28	4.72	5.03	5.58	7.07	3.92	3.24
INS	M	3.10	1.53	1.26	4.79	6.29	1.71	3.03
	<u>SD</u>	4.68	4.97	4.40	5.36	5.58	2.91	2.63
CON	M	1.61	0.16	0.87	1.79	3.83	1.26	2.11
	<u>SD</u>	5.02	5.95	5.03	5.23	6.36	3.83	3.25
OVER	M	2.07	0.18	1.67	2.74	3.99	1.54	2.75
	<u>SD</u>	5.07	5.84	6.83	5.03	5.19	3.68	3.20
FFB	M	4.07	2.71	3.28	4.83	5.77	3.00	4.80
	<u>SD</u>	4.49	5.97	6.76	6.74	5.98	4.05	3.03
Known Concept								
PINS	M	2.50	0.31	1.51	3.03	5.36	1.40	3.39
	<u>SD</u>	6.05	5.83	6.93	7.16	7.94	3.19	3.68
INS	M	1.98	0.24	0.16	3.11	4.84	1.29	2.55
	<u>SD</u>	5.59	5.76	7.19	6.12	5.69	4.43	3.00
CON	M	3.05	0.74	3.03	4.13	5.08	1.41	3.93
	<u>SD</u>	6.48	6.77	7.96	7.59	5.57	5.38	5.58
OVER	M	2.83	0.87	3.72	3.12	4.20	2.23	2.84
	<u>SD</u>	4.66	5.03	6.05	4.51	5.40	2.55	3.95
FFB	M	3.80	1.76	2.89	4.79	6.41	2.32	4.63
	<u>SD</u>	6.33	7.67	6.02	6.41	7.61	5.08	4.80
Distraction								
PINS	M	1.46	1.12	2.23	0.03	2.27	1.20	1.92
	<u>SD</u>	4.85	3.43	7.50	6.60	3.73	3.97	2.73
INS	M	2.70	1.39	3.83	2.95	3.07	2.70	2.26
	<u>SD</u>	3.83	3.94	4.19	5.59	5.02	2.44	2.51
CON	M	1.88	0.83	2.93	1.44	2.19	1.32	2.59
	<u>SD</u>	4.28	3.33	5.99	3.87	5.20	3.70	3.60
OVER	M	2.83	3.16	2.91	2.21	2.68	2.62	3.40
	<u>SD</u>	3.76	4.03	5.25	3.98	4.25	1.85	3.11
FFB	M	0.51	0.02	0.61	1.45	0.14	1.91	1.86
	<u>SD</u>	4.44	3.08	5.77	6.12	4.94	3.02	2.34

Variables	Total	CZ	OZ	F3	F4	P3	P4	
<u>Slide P4 Amplitude</u>								
Experimental								
PINS	M	1.91	1.57	- 4.15	5.57	8.33	- 0.42	0.58
	<u>SD</u>	5.49	3.96	4.69	3.11	3.99	3.43	3.51
INS	M	1.90	0.08	- 2.96	5.33	8.29	0.11	0.56
	<u>SD</u>	5.16	3.10	4.68	3.69	3.87	2.92	3.44
CON	M	0.43	- 0.69	- 3.95	3.13	5.37	- 0.70	- 0.54
	<u>SD</u>	4.54	3.84	3.92	3.02	3.56	3.36	3.29
OVER	M	1.06	- 0.90	- 0.94	3.65	5.65	- 0.85	- 0.16
	<u>SD</u>	5.87	3.50	10.78	3.88	3.58	3.33	3.45
FFB	M	3.26	3.19	- 1.74	6.89	8.73	1.03	1.47
	<u>SD</u>	5.37	4.67	4.21	4.82	4.73	3.30	2.74
Known Concept								
PINS	M	2.87	2.37	- 0.21	3.81	6.75	1.97	2.55
	<u>SD</u>	4.81	4.85	5.92	4.71	4.22	3.77	2.90
INS	M	1.43	- 0.02	- 2.56	4.04	6.57	0.19	0.37
	<u>SD</u>	4.94	3.04	7.19	3.30	3.29	2.98	2.76
CON	M	1.96	1.88	- 1.99	4.90	6.21	- 0.67	1.46
	<u>SD</u>	5.23	4.98	5.73	4.53	4.11	3.88	3.65
OVER	M	1.99	1.28	- 0.69	3.48	5.70	0.38	1.78
	<u>SD</u>	4.08	4.03	5.32	2.73	3.81	2.45	2.59
FFB	M	4.22	2.98	0.70	6.89	8.78	2.34	3.64
	<u>SD</u>	5.60	6.24	5.63	4.48	5.77	3.95	3.73
Distraction								
PINS	M	1.66	2.62	0.18	1.15	3.51	1.08	1.43
	<u>SD</u>	3.67	3.18	6.48	3.22	2.77	2.38	1.99
INS	M	1.68	1.72	1.08	2.68	3.45	0.27	0.85
	<u>SD</u>	3.04	2.57	3.12	3.84	3.02	2.51	2.38
CON	M	2.70	2.69	2.06	3.05	4.15	1.52	2.70
	<u>SD</u>	2.84	3.05	3.89	2.12	3.06	1.99	2.43
OVER	M	2.03	3.22	1.41	2.10	2.55	1.24	1.68
	<u>SD</u>	3.81	4.84	5.38	3.04	2.55	3.41	3.38
FFB	M	1.32	1.44	0.42	1.59	1.72	2.05	0.67
	<u>SD</u>	3.61	3.93	4.73	3.64	3.62	3.11	2.96

Variables	Total	CZ	OZ	F3	F4	P3	P4	
<u>Slide Slow Potential</u>								
Experimental								
PINS	M	- 1.31	- 3.09	- 6.78	3.18	6.28	- 4.38	- 3.07
	<u>SD</u>	5.27	1.80	4.03	2.88	3.04	2.24	1.72
INS	M	- 1.87	- 4.59	6.95	2.99	6.05	- 4.43	- 4.26
	<u>SD</u>	5.66	2.11	4.91	3.20	3.66	2.45	2.16
CON	M	- 3.50	- 5.35	- 7.76	0.02	2.80	- 5.67	- 5.03
	<u>SD</u>	4.80	2.17	4.76	4.10	3.14	2.05	1.66
OVER	M	- 3.21	- 5.45	- 7.66	1.22	3.30	- 6.08	- 4.61
	<u>SD</u>	5.25	2.17	6.03	3.00	3.49	2.12	2.37
FFB	M	- 0.06	- 1.81	- 5.74	3.80	5.51	- 3.60	- 2.70
	<u>SD</u>	5.47	3.81	5.65	3.73	3.91	2.65	2.12
Known Concept								
PINS	M	- 2.43	- 5.30	- 5.16	0.46	3.17	- 4.74	- 3.00
	<u>SD</u>	4.80	2.30	6.00	3.93	3.42	3.29	1.83
INS	M	- 2.47	- 5.04	- 6.48	1.51	4.02	- 4.87	- 3.95
	<u>SD</u>	4.95	2.24	5.99	2.54	2.73	1.78	1.95
CON	M	- 2.68	- 4.99	- 6.12	1.97	2.31	- 5.38	- 3.91
	<u>SD</u>	4.92	2.64	5.66	3.99	3.15	2.97	1.93
OVER	M	- 1.97	- 4.38	- 4.83	0.58	3.84	- 4.40	- 2.93
	<u>SD</u>	4.47	2.24	5.41	2.37	3.93	1.88	2.32
FFB	M	- 1.63	- 4.20	- 4.89	2.15	4.53	- 4.35	- 3.04
	<u>SD</u>	5.42	4.01	5.54	3.35	4.95	3.62	2.92
Distraction								
PINS	M	- 1.16	- 1.37	- 1.65	- 0.67	0.42	- 2.05	- 1.65
	<u>SD</u>	2.76	2.44	4.29	2.57	2.05	2.64	1.74
INS	M	- 0.87	- 0.43	- 1.65	0.05	0.38	- 1.86	- 1.68
	<u>SD</u>	2.58	1.71	3.12	2.74	3.28	1.90	1.95
CON	M	- 0.13	- 0.88	- 1.23	0.29	0.64	0.14	0.24
	<u>SD</u>	2.73	1.97	4.41	1.49	2.42	2.66	2.61
OVER	M	- 0.71	- 0.00	- 1.28	0.16	- 0.03	- 1.52	- 1.60
	<u>SD</u>	3.51	4.67	4.46	2.46	2.87	3.26	3.07
FFB	M	- 1.68	- 2.07	- 2.26	- 0.99	- 1.28	- 1.48	- 2.02
	<u>SD</u>	3.31	3.01	4.99	2.82	3.50	2.05	3.23

Variables	Total	CZ	OZ	F3	F4	P3	P4	
<b>Pre-Feedback CNV</b>								
<b>Experimental</b>								
PINS	M	- 3.38	- 3.19	- 5.88	- 0.79	0.16	- 6.10	- 4.47
	<u>SD</u>	3.52	3.54	3.42	2.57	2.22	2.12	1.65
INS	M	- 3.88	- 4.25	- 6.03	- 1.17	- 0.33	- 6.33	- 5.15
	<u>SD</u>	4.00	3.38	4.74	2.85	3.88	2.20	2.51
CON	M	- 3.71	- 3.81	- 5.75	- 1.62	- 1.03	- 5.39	- 4.68
	<u>SD</u>	3.37	2.66	4.20	2.27	3.45	2.45	2.14
OVER	M	- 3.52	- 4.21	- 5.10	- 1.07	- 0.60	- 5.70	- 4.50
	<u>SD</u>	3.53	2.31	4.12	3.26	3.48	2.64	1.90
FFB	M	- 1.68	- 1.14	- 5.00	2.02	1.48	- 4.22	- 3.20
	<u>SD</u>	4.18	3.56	4.82	3.37	4.32	1.91	1.80
<b>Known Concept</b>								
PINS	M	- 2.99	- 4.01	- 6.08	- 0.11	0.58	- 4.77	- 3.52
	<u>SD</u>	4.46	4.07	6.28	2.77	3.20	3.34	2.35
INS	M	- 2.68	- 3.23	- 5.62	- 0.16	0.36	- 4.13	- 3.33
	<u>SD</u>	3.47	3.08	3.56	1.29	3.52	3.02	1.76
CON	M	- 1.76	- 1.90	- 3.14	0.06	- 0.08	- 3.33	- 2.19
	<u>SD</u>	3.29	2.92	4.05	2.77	3.78	3.50	2.35
OVER	M	- 1.40	- 1.28	- 3.86	0.35	1.26	- 2.96	- 9.90
	<u>SD</u>	3.46	3.40	3.87	3.42	3.01	2.51	1.86
FFB	M	- 2.20	- 2.90	- 4.42	0.80	1.24	- 5.20	- 2.69
	<u>SD</u>	4.96	3.71	4.79	3.29	4.94	6.17	3.33
<b>Distraction</b>								
PINS	M	0.19	0.82	- 2.03	0.97	0.96	0.02	0.39
	<u>SD</u>	3.16	2.79	5.01	2.31	2.66	2.89	2.04
INS	M	- 0.40	- 0.45	- 1.35	0.27	1.24	- 1.09	- 1.01
	<u>SD</u>	2.53	1.70	2.87	3.18	3.17	1.69	1.46
CON	M	1.50	2.05	- 0.23	1.75	3.34	0.72	1.38
	<u>SD</u>	2.86	2.46	2.18	4.63	2.36	2.08	1.69
OVER	M	0.66	1.39	- 0.06	- 0.39	1.75	0.52	0.75
	<u>SD</u>	3.27	3.81	3.82	3.40	3.33	2.64	2.66
FFB	M	- 0.24	- 0.35	- 1.82	1.73	- 0.20	0.02	- 0.82
	<u>SD</u>	4.29	3.09	4.60	7.76	3.48	1.62	2.52

Variables	Total	CZ	OZ	F3	F4	P3	P4	
<u>Feedback N<sub>1</sub> Amplitude</u>								
Experimental								
PINS	M	- 7.76	- 8.29	- 7.11	- 7.41	- 7.64	- 9.09	- 7.01
	<u>SD</u>	2.90	2.62	3.47	2.31	4.43	2.33	1.40
INS	M	- 9.19	- 11.62	- 7.93	- 7.83	- 8.97	- 10.46	- 8.33
	<u>SD</u>	3.70	2.14	4.61	3.75	4.17	3.04	3.10
CON	M	- 10.48	- 13.34	- 9.13	- 9.09	- 9.72	- 11.22	- 10.35
	<u>SD</u>	3.23	2.94	3.34	2.89	3.65	2.36	2.56
OVER	M	- 8.95	- 10.99	- 7.20	- 8.12	- 8.88	- 9.56	- 8.94
	<u>SD</u>	3.55	2.93	3.48	3.09	5.19	2.84	2.71
FFB	M	- 6.56	- 6.99	- 7.75	- 3.75	- 6.10	- 7.98	- 6.80
	<u>SD</u>	4.09	3.88	5.28	3.82	3.79	3.47	3.42
Known Concept								
PINS	M	- 6.97	- 9.09	- 7.01	- 5.81	- 6.10	- 7.66	- 6.15
	<u>SD</u>	3.50	3.84	4.93	2.85	2.21	3.79	2.17
INS	M	- 7.29	- 9.95	- 6.84	- 6.34	- 6.61	- 7.49	- 6.48
	<u>SD</u>	3.27	3.58	3.50	1.94	3.79	3.13	2.49
CON	M	- 7.34	- 9.58	- 6.34	- 6.72	- 6.23	- 8.38	- 6.78
	<u>SD</u>	3.80	3.71	3.53	3.93	4.66	3.49	2.90
OVER	M	- 7.33	- 9.64	- 6.55	- 7.05	- 6.55	- 7.89	- 6.31
	<u>SD</u>	4.08	4.13	4.24	4.37	4.58	3.82	3.07
FFB	M	- 6.85	- 9.05	- 7.49	- 4.76	- 4.88	- 8.04	- 6.90
	<u>SD</u>	4.72	4.02	5.22	3.48	4.81	5.94	3.78
Distraction								
PINS	M	- 5.88	- 7.39	- 5.18	- 5.64	- 6.99	- 5.05	- 4.50
	<u>SD</u>	3.87	4.31	3.96	3.58	4.03	3.76	3.28
INS	M	- 6.66	- 9.37	- 4.63	- 7.66	- 6.86	- 6.15	- 5.28
	<u>SD</u>	4.15	4.75	2.97	4.74	5.16	2.43	3.10
CON	M	- 6.48	- 9.05	- 4.76	- 7.70	- 7.62	- 5.54	- 4.21
	<u>SD</u>	4.10	3.69	2.44	5.60	4.23	3.18	3.18
OVER	M	- 4.95	- 6.78	- 3.35	- 6.57	- 5.54	- 3.94	- 3.54
	<u>SD</u>	4.16	4.80	1.88	4.78	5.02	3.48	3.56
FFB	M	- 6.92	- 8.42	- 5.26	- 8.50	- 7.53	- 5.77	- 6.04
	<u>SD</u>	4.47	6.07	3.77	4.34	4.03	4.05	4.06

Variables	Total	CZ	OZ	F3	F4	P3	P4	
<u>Feedback P<sub>3</sub> Amplitude</u>								
Experimental								
PINS	M	9.58	15.24	5.63	10.46	7.55	8.61	9.98
	<u>SD</u>	5.39	6.24	4.11	5.63	3.89	3.37	3.99
INS	M	9.28	14.28	7.53	8.06	6.50	8.98	10.38
	<u>SD</u>	5.00	4.70	5.16	5.53	3.70	3.93	3.50
CON	M	5.79	8.67	3.12	5.20	6.25	5.09	6.42
	<u>SD</u>	4.15	4.19	4.03	3.84	5.81	1.90	2.79
OVER	M	6.08	8.94	3.95	6.71	5.62	5.23	6.00
	<u>SD</u>	4.19	4.19	5.42	3.69	4.41	3.35	2.76
FFB	M	12.63	19.64	8.73	12.48	8.79	12.40	15.74
	<u>SD</u>	6.64	8.22	4.36	6.03	5.86	4.15	4.73
Known Concept								
PINS	M	5.10	7.33	2.96	5.14	4.69	4.58	5.90
	<u>SD</u>	5.42	7.71	5.56	4.98	3.78	5.16	4.84
INS	M	5.81	7.32	3.15	7.30	6.56	4.93	5.62
	<u>SD</u>	3.73	4.73	5.14	2.43	3.80	1.93	1.80
CON	M	4.36	6.55	3.06	4.81	2.99	3.95	4.78
	<u>SD</u>	3.55	4.67	3.58	3.84	1.99	2.52	2.79
OVER	M	5.08	6.85	3.44	5.17	5.54	4.34	5.16
	<u>SD</u>	2.49	2.26	3.32	1.99	2.39	2.03	1.73
FFB	M	10.32	14.96	7.05	10.30	9.88	8.89	10.83
	<u>SD</u>	6.30	7.61	6.19	6.17	5.74	5.01	5.22
Distraction								
PINS	M	2.82	2.55	1.99	2.72	3.93	2.32	3.44
	<u>SD</u>	3.10	3.26	4.18	2.85	3.62	2.03	2.46
INS	M	4.93	6.31	3.50	4.69	6.34	4.17	4.57
	<u>SD</u>	3.23	3.48	2.89	2.80	3.44	2.91	3.45
CON	M	4.73	6.24	3.33	3.49	5.70	4.60	5.03
	<u>SD</u>	3.32	3.16	2.98	5.40	2.85	1.82	2.21
OVER	M	4.81	6.34	3.85	4.24	6.40	3.86	4.98
	<u>SD</u>	3.42	2.93	4.81	3.10	2.24	3.17	3.06
FFB	M	6.64	9.01	4.69	5.25	6.76	6.51	7.59
	<u>SD</u>	5.08	5.95	6.42	4.51	3.55	4.41	4.99

Variables	Total	CZ	OZ	F3	F4	P3	P4	
<u>Feedback N<sub>3</sub> Amplitude</u>								
<u>Experimental</u>								
PINS	M	0.52	1.56	1.44	1.28	2.27	1.28	2.38
	SD	3.49	3.40	2.80	3.24	4.06	1.92	3.25
INS	M	1.24	1.14	0.67	3.91	4.41	0.43	0.96
	SD	4.38	5.07	3.96	4.18	4.09	3.07	2.90
CON	M	3.43	3.66	3.49	4.09	3.67	3.31	2.35
	SD	2.74	2.19	2.00	2.86	4.04	2.12	1.90
OVER	M	2.51	3.05	2.00	3.28	3.66	2.01	1.05
	SD	2.95	3.56	3.04	2.29	3.73	2.15	2.30
FFB	M	2.84	4.93	3.18	1.03	2.21	4.57	5.55
	SD	5.92	7.21	4.02	5.12	5.48	4.24	6.11
<u>Known Concept</u>								
PINS	M	3.08	2.95	4.49	2.58	3.10	3.30	2.08
	SD	4.01	4.63	4.90	4.27	3.82	3.49	3.26
INS	M	2.59	2.47	3.52	2.54	2.97	2.39	1.64
	SD	2.55	3.06	3.39	1.65	2.68	2.40	1.89
CON	M	3.35	3.29	4.23	3.39	2.85	3.09	2.66
	SD	2.59	2.42	3.28	2.62	3.14	2.56	1.46
OVER	M	3.10	3.22	3.96	3.04	2.87	3.03	2.50
	SD	2.58	1.41	3.88	3.43	2.70	1.40	1.89
FFB	M	0.74	1.92	0.33	1.06	0.12	1.09	0.58
	SD	5.91	7.48	5.43	4.70	5.87	5.87	6.89
<u>Distraction</u>								
PINS	M	3.73	4.61	4.58	4.61	3.37	2.54	2.69
	SD	3.01	3.78	3.08	3.40	3.18	2.01	2.03
INS	M	3.19	3.88	2.90	3.45	3.23	3.06	2.61
	SD	3.24	3.51	2.95	4.21	3.85	2.79	2.44
CON	M	2.18	2.15	2.95	2.70	1.96	2.04	1.26
	SD	2.32	2.05	2.19	3.77	1.86	2.14	1.33
OVER	M	2.69	2.82	2.90	4.24	1.87	2.69	1.64
	SD	3.41	3.49	2.47	4.59	4.12	2.80	2.57
FFB	M	3.26	3.26	4.30	3.51	3.61	2.93	1.91
	SD	5.68	7.18	4.61	7.99	4.12	5.11	5.13

Variables	Total	CZ	OZ	F3	F4	P3	P4	
<u>Feedback P<sub>4</sub> Amplitude</u>								
Experimental								
PINS	<u>M</u>	4.34	5.60	5.55	3.25	1.90	4.99	4.77
	<u>SD</u>	3.89	2.91	4.26	3.41	3.71	2.96	5.06
INS	<u>M</u>	3.23	4.65	4.70	1.03	0.70	4.02	4.29
	<u>SD</u>	4.19	4.85	4.62	3.51	3.95	3.20	3.47
CON	<u>M</u>	1.88	3.03	1.89	1.14	1.12	1.79	2.32
	<u>SD</u>	3.05	3.38	3.03	2.48	4.14	2.19	2.95
OVER	<u>M</u>	2.27	2.95	2.88	1.12	1.07	2.47	3.12
	<u>SD</u>	3.99	4.59	4.69	2.65	4.69	3.61	3.66
FFB	<u>M</u>	6.85	8.78	7.91	5.64	2.49	7.53	8.76
	<u>SD</u>	5.90	7.36	6.20	4.51	4.10	5.20	6.08
Known Concept								
PINS	<u>M</u>	2.24	1.77	2.58	2.18	1.75	2.18	2.96
	<u>SD</u>	3.10	3.06	4.28	3.26	3.01	2.92	2.32
INS	<u>M</u>	2.94	2.53	4.34	2.54	2.15	2.55	3.52
	<u>SD</u>	2.83	1.89	3.75	2.08	3.32	3.42	1.89
CON	<u>M</u>	2.46	2.55	3.44	1.82	2.00	2.32	2.64
	<u>SD</u>	2.28	2.83	2.87	1.89	1.88	2.03	2.15
OVER	<u>M</u>	2.66	3.01	3.06	1.44	2.67	2.61	3.16
	<u>SD</u>	2.51	2.65	2.50	2.47	3.49	1.90	1.87
FFB	<u>M</u>	7.09	8.25	6.60	6.52	5.96	6.24	8.97
	<u>SD</u>	5.65	6.61	7.18	3.54	5.36	4.61	6.44
Distraction								
PINS	<u>M</u>	2.00	1.83	2.25	1.51	2.04	2.03	2.33
	<u>SD</u>	2.66	3.63	3.05	2.39	3.14	1.93	1.94
INS	<u>M</u>	2.81	3.44	1.63	3.14	3.79	2.19	2.66
	<u>SD</u>	2.74	2.59	2.54	3.64	2.83	2.54	2.07
CON	<u>M</u>	3.64	4.10	3.14	3.96	3.75	3.14	3.77
	<u>SD</u>	2.24	2.62	2.39	2.50	2.53	1.71	1.88
OVER	<u>M</u>	3.89	4.53	3.65	2.34	4.91	3.83	4.10
	<u>SD</u>	3.50	3.57	3.66	3.49	4.10	3.29	3.07
FFB	<u>M</u>	4.12	5.48	2.72	3.22	3.97	4.13	5.20
	<u>SD</u>	4.07	4.43	5.76	4.45	3.04	3.28	2.91

Variables	Total	CZ	OZ	F3	F4	P3	P4	
<u>Baseline Offset</u>								
Experimental								
PINS	M	0.92	1.55	0.24	1.31	2.28	0.54	1.15
	<u>SD</u>	3.68	3.73	3.74	4.14	4.68	2.67	2.75
INS	M	0.01	0.23	0.45	1.33	0.65	0.24	0.18
	<u>SD</u>	3.74	2.71	3.41	4.14	5.86	3.12	2.85
CON	M	1.09	0.85	1.41	0.06	1.99	0.76	1.49
	<u>SD</u>	4.44	4.53	2.40	6.00	6.84	3.01	2.74
OVER	M	1.19	1.32	3.05	0.29	0.53	0.91	1.60
	<u>SD</u>	5.05	6.02	4.15	5.22	6.39	4.34	4.29
FFB	M	4.91	6.97	4.00	2.78	6.06	4.49	5.59
	<u>SD</u>	5.72	6.22	4.86	6.32	6.56	5.71	4.86
Known Concept								
PINS	M	0.63	0.18	2.27	1.59	0.33	1.25	1.35
	<u>SD</u>	6.35	6.42	5.99	7.38	9.52	3.87	3.95
INS	M	0.88	0.55	3.04	0.59	0.00	1.28	1.00
	<u>SD</u>	6.41	6.10	5.16	8.00	9.93	4.28	3.72
CON	M	1.91	2.74	2.40	4.26	4.64	2.19	0.09
	<u>SD</u>	6.71	6.67	5.45	7.36	8.93	5.72	3.55
OVER	M	0.59	1.89	3.44	2.94	1.84	1.07	1.90
	<u>SD</u>	5.03	4.03	2.87	5.34	7.91	2.96	2.61
FFB	M	3.32	3.10	4.17	2.58	4.58	2.29	3.21
	<u>SD</u>	6.22	5.97	5.59	8.29	7.90	4.75	5.12
Distraction								
PINS	M	0.47	0.56	2.74	2.51	3.08	0.49	0.13
	<u>SD</u>	4.84	5.23	6.39	4.91	4.31	2.90	2.85
INS	M	1.34	0.83	0.06	2.93	2.66	1.10	0.60
	<u>SD</u>	4.55	4.72	3.01	6.98	4.89	3.66	3.11
CON	M	1.01	0.84	1.08	0.75	2.10	0.63	0.64
	<u>SD</u>	3.04	2.84	2.55	4.40	3.90	2.01	2.27
OVER	M	1.69	1.85	1.47	2.21	1.66	1.67	1.24
	<u>SD</u>	3.26	4.04	3.23	3.91	4.19	1.78	2.34
FFB	M	0.90	1.30	0.61	1.71	0.69	1.69	0.61
	<u>SD</u>	4.14	3.25	5.95	5.99	3.28	2.88	2.52

APPENDIX 5

MEANS AND STANDARD DEVIATIONS FOR CLICK (WS)  
N<sub>1</sub>, P<sub>2</sub>, P<sub>3</sub> AND SLIDE N<sub>1</sub> - P<sub>2</sub> MEASURED  
AT CZ FOR ALL CONDITIONS AT EACH SEQUENCE STAGE

Means and Standard Deviations for Click (WS)  
 $N_1$ ,  $P_2$ ,  $P_3$  and Slide  $N_1 - P_2$  Measured  
 at CZ for all Conditions at each Sequence Stage

Sequence x Condition	Variable									
	Click						Slide $N_1 - P_2$			
	<u>M</u>	<u><math>N_1</math></u>	<u>SD</u>	<u>M</u>	<u><math>P_2</math></u>	<u>SD</u>	<u>M</u>	<u>SD</u>		
Preinsight										
Experimental	9.45	2.50		3.66	3.40		5.19	3.70	13.43	6.34
Known Concept	- 7.18	3.94		6.76	4.35		2.78	4.86	13.57	6.53
Distraction	- 9.31	3.15		4.40	3.84		3.94	5.32	11.48	6.57
Insight										
Experimental	- 8.94	2.64		4.23	3.88		3.65	2.82	13.34	7.76
Known Concept	- 9.49	4.17		6.86	5.19		4.40	4.03	14.58	6.34
Distraction	- 8.52	3.24		4.40	4.30		3.60	3.98	11.39	6.16
Confirm										
Experimental	- 8.20	2.41		4.40	4.73		3.70	3.92	13.05	6.78
Known Concept	- 8.80	4.35		6.85	2.96		5.32	5.42	13.47	6.67
Distraction	- 7.18	2.32		3.47	3.89		4.58	4.58	11.99	6.39
Overlearn										
Experimental	- 8.75	3.43		3.89	3.48		4.95	3.29	13.26	7.12
Known Concept	- 9.45	2.82		6.57	4.30		3.66	5.60	14.03	7.32
Distraction	- 8.15	2.22		4.40	4.55		4.40	3.80	12.13	6.81
False Feedback										
Experimental	- 9.54	3.75		4.68	5.51		5.09	4.49	13.62	6.24
Known Concept	- 8.98	4.03		6.07	5.23		4.17	4.69	14.08	6.76
Distraction	- 8.38	4.40		5.09	3.88		3.52	4.73	11.58	6.07