THE EFFECTS OF OUTCOME OF DECISION, TASK RELEVANT INFORMATION, SURPRISAL, INCENTIVE, AND VALUE ON THE HUMAN EVOKED POTENTIAL

Kenneth B. Campbell

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

Ottawa, Canada, 1976

ProQuest LLC
789 East Eisenhower Parkway
P.O. Box 1346
Ann Arbor, MI 48106-1346

ACKNOWLEDGEMENTS

This thesis was prepared under the supervision of Terence W. Picton, M.Sc., M.D., Ph.D. Not only did he introduce me to evoked potentials, teaching everything I know about this exciting field of research, supervising the smallest of methodological details, and being more than generous with his time, talent, and dedication, he also provided inspiration and enthusiasm when the going became particularly rough.

My sincerest thanks are also extended to Drs. William F. Barry, Lawrence Dayhaw, Charles McInnis, and Robert Stelmack, whose continued interest and criticisms of the methodological and statistical problems proved to be invaluable.

A large portion of the technical problems were shouldered on Edwin Achorn and Robert Schieman who spent many months developing the computer program that controlled the experimental procedure. Additional assistance was provided by Pierre Boudreault and Robert Spratt. Thanks also to Lucie Côté for serving long hours as a subject, helping with the scoring of the physiological data and preparation of tables, as well as proofreading the final draft.

Last, but certainly not least, I am especially grateful to an enormously competent colleague, Donald T. Stuss, with whom close collaboration was made on almost all phases of this study. Simple words cannot nearly convey the admiration I hold for him as a scholar and a friend.

CURRICULUM STUDIORUM

Kenneth B. Campbell was born June 22, 1948, in Saint John, New Brunswick. He received the Bachelor and Master of Arts degrees from the University of Ottawa, Ottawa, Ontario, in 1970 and 1974 respectively. The title of his Master's thesis was, Introversion-Extraversion and Auditory Sensitivity to High and Low Frequency Tones.

ABSTRACT

The Effects of Outcome of Decision, Task Relevant Information, Surprisal, Incentive, and Value on the Human Evoked Potential

Kenneth B. Campbell

University of Ottawa

A time estimation task was developed to test the hypothesis that disconfirmation would be associated with larger P3 components of the evoked potential than confirmation regardless of its probability of occurrence. The experimental paradigm was such as to permit the criterion for successful (correct) estimation to be varied, thereby manipulating probability of occurrence of either confirming or disconfirming feedback. In some conditions feedback was irrelevant, not being based on subject performance but rather on a random, probability schedule.

The amount of information contained in the signal was calculated in two ways, (1) "surprisal," based on the strict logarithmic measure of improbability of its occurrence and (2) "task relevant information," based not only on improbability of occurrence but also taking into account the relevancy of the stimulus in providing actual feedback information.

At the vertex, amplitude of P3 was found to be closely related to the degree of task relevant information in the stimulus, whether this stimulus informed the subject of confirmation or disconfirmation, and only slightly related to surprisal. Irrelevant stimuli significantly attenuated P3 amplitude. This same effect was noted as early as the onset of P2, suggesting that it may index the initial stage of decision processing. P2 and P3 moreover shared some degree of common variance as did also a still later positive component, P4. P3, however, differed from P4 in that it (P3) showed a wider scalp distribution than P4, which was largely centered in parietal zones. Frontally, disconfirmation was linked to larger P3 components than confirmation suggesting that the LPC originates from several sources rather than being a unitary phenomenon. The frontal P3- parietal P4 provides some support for the travelling "wave of positivity" hypothesis.

Incentive or monetary value attached to a particular feedback signal had almost no effect on any of the components. Comparisons across the three days of experimentation pointed to a significant increase in pre-feedback CNV from Day 1 to Day 3, perhaps due to decreased anxiety associated with familiarisation with the experimental situation. Similarly P3 also increased in amplitude over the three days. However, except for this relationship, P3 and the CNV were found to share almost no common variance, experimental manipulations affecting P3 failing to affect the CNV. CNV and P3 then appear to be independent from one another.

Behaviourally, the error associated with the time estimations significantly increased when feedback was irrelevant. Feedback then served the purpose of allowing the subject to compare what was planned with what actually happened, providing for error correction. Over the three days of experimentation, a non-significant decrease in time estimation was observed when feedback was task relevant. When it was not, the decrease in error was significant,establishing stronger evidence for a type of learning or carry over effect from condition to condition and from day to day.

TABLE OF CONTENTS

LIST OF TABLES

Table page

LIST OF FIGURES

into the brain but into the mind" (p.243). One such excursion has been into an investigation of the cortical response to confirming and disconfirming feedback. Typically the effects of disconfirmation have been much greater than confirmation, the interpretation of this result being far less consistent. Two popular hypotheses have been: firstly, disconfirmation, in these experiments, has been less probable than confirmation, and thus more unpredictable or more informative (following information theory -- Shannon and Weaver, 1949); secondly, disconfirmation, in its demands for further evaluation of previously formed hypotheses, requires greater cortical involvement to analyze its significance. A primary aim of this study will be to resolve this controversy.

In addition, the study will attempt to investigate the role of relevancy of feedback and the amount of task relevant information contained in the feedback signal on behavioural performance and the waveform of the evoked potential. The effects of varying incentive and monetary value placed on a particular stimulus will also be determined. Research in the Soviet Union and in the United States have placed feedback-related activity in the frontal zones of the cortex. The amplitude of the late positive component in other research however, has been shown to be maximum in posterior regions. To examine if the feedback response is a unitary cortical phenomenon or an independent source, a multiple electrode placement will be employed. Finally, whether feedback is effective in producing improvement in the behavioural task will be investigated, and if so, whether the waveform of the evoked potential mimics these changes.

In order to manipulate the independent variables, a time estimation task will be employed. The effects of surprisal will be tested by varying the probability of obtaining confirming feedback, the likelihood being either low, medium, or high. On other conditions feedback will vary in the degree to which it is "task relevant"; in some instances it will be irrelevant, not being contingent on the subject's actual performance. Incentive and value will be manipulated by providing various payoff matrices. Electrical activity will be recorded from three topographical sites, frontal, central, and parietal locations.

The first chapter of this study contains a review of the theoretical background and relevant research findings which led to the formulation of the hypotheses to be investigated. The second chapter describes the sample, the instruments, procedure, methodological problems, and the statistical analyses employed in the testing of the hypotheses. The third chapter presents the results and provides a brief interpretation while the final chapter discusses the results in greater detail in relation to the theoretical problems posed in Chapter One. A summary and conclusions of the research is also presented.

CHAPTER I

Review of the Literature

Knowledge of Results

Knowledge of results (KR) of action has important effects on the performer and his future behaviour. It was Thorndike (1931) who has generally been credited with the establishment of significant interest in KR as a vehicle for research in learning. He had subjects produce a line of fixed length and defined the correct response at some arbitrary level of accuracy. Saying "right" after a correct response acted as a rewarding event causing the subject to acquire the desired response, and saying "wrong" acted as a punishing event that caused an incorrect response to drop out.

Elwell and Grindley (1938) did several experiments on KR with motor behaviour. They made the observation that a human subject does not repeat rewarded responses as animals seem to do. Rather, on the next trial he attempts to correct his errors. An unsuccessful movement results in a variation in the response just made, not its repetition. Thorndikian, S-R interpretation requires a repetition of reinforced responses and avoidance of punished ones, but there is no accounting for improvement in performance based on systematic correction of error.

The term, "feedback", taken from cybernetics has more or less replaced "KR" in common usage today. Theories of feedback activity however date from the time of James (1890). James developed a chaining hypothesis to explain voluntary movement, in which the next response segment of a movement sequence was conditioned to the response produced stimuli of the last sequence. This was called the hypothesis of serial action. The research of Lashley and his associates (Lashley, 1917,1951; Lashley and Ball, 1929;Lashley and McCarthy, 1926) was a reaction against the response chaining hypothesis, leading them to conclude for the alternate hypothesis of motor programming. A central plan for sequence is laid down in learning and is capable of running off the sequence without help of proprioceptive feedback. Lashley's procedures however did not block all feedback channels, his rats thus perhaps navigating a maze by using various combinations of other sensory feedback loops.

Another point of view is that feedback is a performance, not a learning variable (Briggs, Fitts and Bahrick, 1957). This hypothesis is rooted in the traditional distinction between associative (learning) and nonassociative (performance) states, which is a distinction more recent than the response chaining idea and independent from it. Empirically, a performance variable is a momentary determiner of behaviour, with no persistence from prior experience as a learning variable would have.

Engineering psychologists have been prominent in their attempts to use closed-loop or servo-theory for the description of tracking behaviour. Open-loop systems, so conspicuous in the Thorndikian-Lashley and modern behaviourist schools of thought, have no feedback or mechanisms for error regulation. The input from the environment exert their influence, the system effects its transformation on the input and the system has an output. A poorly operating open-loop system (error) is due to the characteristics of the input and/or the transformations imposed by the system. Regulatory adjustment of the organism by feedback from the response output ordinarily is not available.

To qualify as a closed-loop, a theory must be error-centered, with a reference mechanism against which feedback from the response is compared for the detection and correction of error. Besides engineering and cybernetics, other influences on closed-loop theory were from experimental phonetics (Fairbanks, 1954) and medicine (Chase, 1965a, 1965b).

More direct and explicit closed-loop theorizing for learning comes from the Soviet Union (Anokhin, 1961, 1969; Sokolov, 1963). The gist of the Soviet position is that all impinging stimuli whether they be environmental or feedback imprint what Anokhin calls the "acceptor of action" and what Sokolov calls the "neural model" or "image". The orienting reflex is an investigating response that searches the environment and it can be interpreted as the organism's attempt to eliminate error.

Bernstein (1967) wrote similarly about motor behaviour. Feedback from the response enters a comparator where it is tested against the ideal one in the command center and the result can be an error signal and a correction. Bernstein has the image or neural model as the central command agent which defines the response that is fired and which is the reference against which feedback is tested. James (1890) and Greenwald (1970) also use the image as the central representation which defines the response.

Adams (1968) and Adams and Bray (1970) noted a flaw in this approach. The Soviets failed to account for error detection despite the concern for it. The model which defines and fires the response is also the mechanism for verifying it. Thus, the response checks itself. However, the agent that fires the response and the model that tests it must be different because without the difference we would not know that an error had occurred. The Adams' closed-loop theory of self-paced motor behaviour assumes that any stimuli, including response feedback stimuli, imprint a perceptual trace (similar to neural model) with some persistence. The strength of the trace is a function of amount of feedback stimuli and the exposure to them. On any particular trial, feedback stimuli from the ongoing responses are compared against the perceptual traces of previous responses, and so both stimuli which persist from past trials through learning as well as momentary stimuli of the current trial determine behaviour, giving feedback a learning and performance role. If the perceptual trace becomes strong enough after a large number of trials, the correct response can be maintained by the reference without external KR (Adams and Bray, 1970, Bilodeau and Bilodeau, 1958). For James this was the stage at which "conscious" behaviour became automatic.

One of the most consistent findings of the research literature in psychology is that KR improves performance in a number of tasks (see

Ammons, 1956; Annett, 1969; and Bilodeau, 1966 for reviews). The rate of improvement depends upon the precision of KR (Baker and Young, 1960; Bilodeau, Bilodeau, and Schumsky, 1959; MacPherson, Dees, and Grindley, 1948; Rogers, 1974; Thorndike, 1927; Trowbridge and Cason, 1932). KR can be classified as qualitative or quantitative. Oualitative KR is dichotomous, like the experimenter saying "Right" and "Wrong". Or the equipment analogue of "Right" and "Wrong" might be used, such as a green light for a correct response and a red light for an incorrect one. Quantitative KR differs in the way of providing scaled information, such as, "You moved 10 cm too far to the left".

Trowbridge and Cason (1932) employed irrelevant, qualitative, and quantitative KR, accuracy significantly increasing with the greater improvement provided by the KR. Bilodeau and Rosenbach (1953) on the other hand, found few effects from varying feedback precision.

In vigilance tasks (Mackworth, 1964) when monitoring of a task signal is extended over a period of time, KR after each response or failure to respond prevented vigilance decrement. KR in these vigilance tasks may be associated with motivation. The general conclusion now is that while subject sensitivity remains constant, the response criterion varies, KR causing it to remain much more stable (Annett and Paterson, 1966; Broadbent, 1958; Buckner and McGrath, 1963). Adams and Bray (1970, p.396) have stated that error is motivating. Indeed a complete series of studies have been carried out showing that KR is motivating (see Locke, Cartedge, and Koeppel, 1968, for a review).

The marked consensus in a wide variety of perceptual and motor studies then seems to be that KR or feedback is effective in improving performance. Withdrawal of KR produces deterioration of performance when level of training is low or moderate (Bilodeau et al., 1959; Boulter, 1963; Rogers, 1974; Schumasky, Grasha, and Seymann, 1966). The position thus is that KR is foremost a source of information which results in corrections that eventually lead the subject to a correct response. That feedback is information to a problem-solving subject means that the subject operates on the feedback and often will use it to form the hypotheses for future strategies.

As such, the closed-loop theory emphasizes cognitive activity. Miller, Galanter, and Pribram (1960) have charted a closed-loop model of information processing that allows for a thermostat-type mechanism for error correction--the TOTE system. Quite recently, Pribram (1971) has modified this position to include a "feedforward" exit that appears to utilize feedback to bias future incoming events.

The present study examined the effects of KR or feedback on the behavioural performance in a particular task involving the estimation of a short time interval. One of the focal points was an attempt to investigate the brain mechanisms underlying the basis of feedback activity.

Numerous observers (Anokhin, 1969; Bernstein, 1967; Luria, 1966a, 1966b; Pribram, 1960) have described the frontal cortex as essential for any organized action. Without the feedback mechanism, labelled the "action acceptor" by Anokhin, any form of organized behaviour is impossible.

Upon destruction of the frontal lobes, an animal is unable to assess and correct errors it has made. For this reason the behaviour of an animal without its frontal lobes loses its organized and purposive character (Pribram, 1960, 1961). "The frontal lobes not only perform the function of synthesis for action, and formation of programmes, but also the function of allowing for the effect of the action carried out and verification that it has taken the proper course" (Luria, 1973, p.93). This type of regulation takes place with the close participation of speech, which of course, is mostly highly developed in the human being. Human patients with massive lesions of the frontal lobes not only lose the logic of a task, but also fail to notice their mistakes. Thus, they lose control over their actions as well as the ability to check their results (Luria, Pribram, and Homskaya, 1964).

The parietal lobe, being an association area, is viewed by Pribram (1970) as being responsible for expanding the stimulus field being sampled at a slow rate and integrating the diverse information obtained. Luria (1966a, 1966b) and Das, Kirby, and Jarman (1975) state that these zones carry out simultaneous processing. Any portion of the result is at once surveyable without dependence upon its position in the whole.

To assess cortical functioning in humans, a variety of physiological techniques have been employed, including encephalographic and averaged evoked response recordings. The averaged evoked response (AER) has been the focus of extensive research in the last twenty years. The validity and usefulness of the technique in numerous contexts in almost certain. Since Dawson's (1954) initial observations of the AER, a great deal of effort has been paid to these minute brain potentials. At first, the general assumption was that the AER was a cortical representation of the sensory neural impulses evoked by a stimulus. More recently, work has indicated that, in addition to signalling cortical reception of sensory stimuli, the AER also reflects aspects of intracortical processing underlying complex psychological factors.

Evidence is available which suggests that scalp recording is a cogent reproduction of activity on the surface of the cortex (Broughton, Rasmussen, and Branch, 1968; Cooper, Winter, and Crow, 1965; Domino, Matsuoka, Waltz, and Cooper, 1964; Heath and Galbraith, 1966). Cooper et al. (1965) reported ratios of cortical to scalp voltage as low as 2:1 for the late, diffuse components. It is these late nonspecific components of the AER that were examined at a variety of scalp locations in this study. Experimental manipulations attempted to investigate the relationship of feedback to a number of variables.

The Vertex Potential

A sequence of early and middle latency components (less than 50 ms) may be observed in the evoked potential recorded from the vertex of the scalp, representing brainstem and thalamic projections. A series of late waves (50-250 ms) are characteristically called the "vertex potential" (Davis and Zerlin, 1966; Davis, Mast, Yoshie, and Zerlin, 1966). These have been designated as P1, N1, P2, and N2, "P" and"N" compendia for the positive and negative valence that the components take, peaking at 50, 80, 175 and 300 ms respectively with auditory stimuli (Picton, Hillyard, Krausz, and Galambos, 1974b) and being maximally distributed over anterior regions being largest at the vertex (Goff, Matsumiya, Allison, and Goff, 1969; Kooi, Tipton, and Marshall, 1971; Picton et al., 1974b). With visual stimuli, the components peak approximately 50 ms later depending on stimulus intensity, being distributed posterior-occipitally (Simson, Vaughan, and Ritter, 1976; Vaughan, 1966, 1969b). Because of its relatively large amplitude (approximately 5-30μV) the vertex potential likely originates in the cortex rather than the thalamus or the brainstem. Recordings from human frontal cortex support this claim. Walter (1964) and Weinberg, Walter, and Crow (1970) reported auditory evoked potentials that seemed precisely homologous to human scalp recordings.

The vertex potential has been termed a sensory evoked potential in the sense that its latency and amplitude is controlled mainly by the stimulus. Several studies have been concerned with the roles of stimulus quality (e.g., intensity and frequency), vigilance, arousal, and voluntary attention on the vertex potential. Although the present study was primarily interested in the psychological related components, certain manipulations were expected to influence the N1-P2-N2 components of the vertex potential. A brief review will thus be made of the sensory-evoked vertex response.

A wide range of research has examined the behaviour of the N1-P2 peak during tasks in which attention is directed towards a particular target stimulus. A primary function of the nervous system is to select limited significant information from the environment and exclude other irrelevant stimuli. Tasks devised to induce attention include: simple verbal instructions to "attend" to one stimulus and "ignore" others, instructions to count stimuli to be attended, or complex discrimination and vigilance tasks. The usual finding is that the amplitude of the vertex potential is enhanced to the stimulus to which attention is directed. Due to methodological complications, the controversy has taken more than a decade to resolve and still doubt lingers (Naatanen, 1975).

Early research by Hernandez-Péon and Donoso (1959) and Jouvet, Schott, Couyon, and Allègre (1959) indicated that distracting tasks substantially reduced the amplitude of the evoked response recorded from brainstem electrodes. Satterfield (1965) alternated clicks with painful cutaneous shocks. In one series the subject had to report the occurrence of occasional lower intensity clicks while ignoring the constant intensity shocks and in another series to perform an equivalent task when shocks varied in intensity and clicks were constant. Amplitude was larger for the modality attended. Spong, Haider, and Lindsley (1965) employed three methods to vary attention. In an alternating series of clicks and flashes, the subject either responded to a change in the intensity of the attended modality, responded (keypressing) after each stimulus of the attended modality, or counted the stimuli and responded after fifty. Results again confirmed increased amplitude for the attended modality, except for the counting condition. However, Jouvet et al. (1959), Garcia-Austt, Bogacz, and Vanzulli (1964), and Gross, Begleiter, Tobin, and Kissen (1965), all noted positive effects in the expected direction when the subject was required to count the stimuli.

Chapman and Bragdon (1964) and Chapman (1965) have observed that the amplitude of the vertex potential is enhanced by meaningful stimuli. Later, Sheatz and Chapman (1969) alternated two tone and two noise bursts, both varying in frequency. On a particular series, the subject had to decide whether the second stimulus of a particular modality varied from the first stimulus of that modality. The amplitude of the P2 component was significantly heightened by the relevant stimulus.

There were, however, two basic problems with these early studies: the control of sensory input and the evaluation of changes in non-selective arousal mechanisms. Experiments such as those of Hillyard and his colleagues (Hillyard, Hink, Schwent, and Picton, 1973; Picton and Hillyard, 1974) have carefully investigated stimulus input control (Worden, 1966). With control of stimulus input there is no change in the early components of the evoked potential but only in the later vertex potential components. The other problem with many of the early studies concerns the possibility of changes in non-selective arousal levels which might have enhanced any stimulus response and not selectively enhanced the attended stimulus response.

The occurrence of the relevant (attended) and irrelevant (ignored) stimuli was predictable, thus subjects might have altered their state of arousal phasically in anticipation of the known stimulus. Naatanen (1967) has suggested that the irrelevant stimulus serving as a warning signal triggered a state of general alertness "as an anticipatory and preparatory reaction to a relevant stimulus immediately prior to and at its presentation" (p.46). Modifying the Spong et al. experiment, by presenting the relevant and irrelevant stimuli in a random fashion making prediction of the relevant stimulus impossible, no enhancement of the vertex potential was seen. Hartley (1970) and Smith, Donchin, Cohen, and Starr (1970), employing similar procedures also reported a failure to find differences in the amplitude of the vertex potential invoked by stimuli that were attended or ignored. Hartley, however, pointed out a weakness in these studies. "Stimuli are presented at such a slow rate that it is well within the subject's capacity to handle the information on both channels should they wish to do so, even if experimental instructions do not require it" (p.544). In other words, subjects were able to attend to both relevant and irrelevant stimuli because of the slow presentation rate.

Wilkinson and Lee (1972) forced subjects to selectively attend to a relevant stimulus by presenting a random sequence of tones at a very rapid rate (mean= 1.5 Hz). The amplitude of the vertex potential evoked by the relevant stimulus was augmented by 10%. Picton, Hillyard, Galambos, and Schiff (1971) and Hillyard et al. (1973) presented relevant and irrelevant stimuli into both ears at a very rapid rate, effectively restricting attention to one channel at a time. Whether a binaural click discrimination (Picton et al., 1971) or a frequency discrimination task (Hillyard et al., 1973), results were the same--an increase in the N1 wave to stimuli in the attended ear.

Both long and short term habituation of the vertex potential occur. Long term habituation has been investigated via vigilance tasks, duration ranging from one to fifteen hours.

Haider, Spong, and Lindsley (1964) noted that for nonrelevant stimuli, amplitude of the P2 component declined systematically over an 80 to 100 minute period. Wilkinson, Morlock, and Williams (1966) and Wilkinson and Morlock (1967) also reported a decline in amplitude of P2 over a two hour period as well as an increase in the later N2 component, possibly related to drowsiness. Further evidence for attenuation in P2 during vigilance comes from Garcia-Austt (1963) and Garcia-Austt (1964).

A problematic issue in vigilance tasks surrounds the level of alertness of the subject. Roeser and Price (1969) argued that habituation should not be considered to be a general decrease in alertness but rather a slow and progressive decrease in amplitude of the response, alertness being maintained for other novel stimuli. It is impossible to disentangle the effects of decreasing alertness and habituation in the above studies. When Roeser and Price did maintain constant alertness, they found clear evidence of long-term habituation. Indeed after the first half hour, the process is completed, a finding replicated by MacLean, Ohman, and Lader (1975) and Picton, Hillyard, and Galambos (in press). Other research has indicated that habituation is dependent on a number of variables: intensity of the stimulus (Davis and Heninger, 1972; Rose and Ruhm, 1966), or length of the interstimulus interval (Butler, 1972; Milner, 1969; Nelson and Lassman, 1968; Ritter, Vaughan, and Costa, 1968; Rothman, Davis and Hay, 1970).

Thus, the amplitude of the vertex potential process is dependent on both stimulus parameters and attentional manipulations.

> [It] may represent the activation of neural assemblies involved with the analysis of incoming auditory information, the extent and nature of which is determined by the stimulus and by the nature of the attentional process required. (Picton and Hillyard, 1974, p.197).

Contingent Negative Variation (CNV) and Slow Waves

Following the vertex potential evoked by a warning signal, S1, and prior to a stimulus requiring a response, S2, a slow negative D.C. baseline shift develops. Walter and his colleagues (1964a) were the first to describe this baseline shift, terming it the "contingent negative variation" (CNV). Confirmation and replication of Walter's discovery was made by Cohen, Offner, and Blatt (1965), Low, Borda, Frost, and Kellaway (1966) and Rebert, McAdam, Knott, and Irwin (1967). Since that time it has been reported to be a correlate of expectancy, attention, motivation, and conation. In about one-third of normal subjects, the CNV can be seen in "raw" EEG records. Usually it is studied by averaging techniques requiring a maximum of 30 trials to be seen (Cohen, 1969) although in some cases 5 trials (Jus, Kiljan, Kubacki, Rzepecki, Wilczak, and Jus, 1968) and 8 trials (Hillyard, 1969) were sufficient.

While a motor response to S2 usually helps to develop clear CNVs, it is not absolutely necessary. Walter (1966) and Cohen and Walter (1966) have demonstrated that merely making a mental response was sufficient, leading the authors to postulate expectancy as the single most psychological correlate. The concept of "cortical priming", often employed as a rationale for the expectancy wave, is not restricted to preparation for a motor act, but can also include a preparatory perceptual set (Loveless, 1973; Loveless and Sanford, 1974). Two types of CNV have been differentiated on the basis of rise time of the negative ascending limb: one, a quick rise to peak and the other a gradual rise with a "negative ramp" shape (Cohen, Offner, and Palmer, 1967) and have been designated Types A and B respectively (Tecce, 1972). Type A CNVs have been found when subjects are uncertain about the time of occurrence of S2, and type B CNVs when there is a high level of certainty (McAdam, 1969). This raises the fundamental question of whether the CNV is a unitary and generalized phenomenon or whether it can be subdivided into classes of slow potential shifts specific to particular psychological operations (Borda, 1970; Cant and Bickford, 1967).

A "readiness potential" described by Kornhuber and Deecke (1965) and Gilden, Vaughan, and Costa (1966) resembles a Type B CNV. It begins 0.5 to 1.0 second before voluntary spontaneous hand or foot movements and peaks at the time of response. Its maximum response is seen over the pre- and post-central gyri over the cortex contralateral to the moving joint (Gerbrandt, Goff, and Smith, 1973). McAdam and Whitaker (1971) found that a readiness potential also precedes spontaneous speech and is of higher amplitude in the left frontal region, over the speech center. Because of the similarities between the CNV and the readiness potential, Gilden et al. (1966) and Vaughan (1969a) suggested that the CNV may be an indication for preparation of movement. However, as stated previously, CNV has occurred in the absence of a motor response, unlike the readiness potential, and has followed a different lateral topography, CNV being bilaterally symmetrical (Cant, Pearson, and Bickford, 1966; Cohen, 1968; Low, Frost, Borda and Kellaway, 1966).

Although CNV has been shown to accompany a number of behavioural acts, there is little correlation with specific parameters of performance. The most commonly studied variables have been motivation and attention-arousal. The only definite conclusion one can make regarding the CNV and its relationship to psychological variables is that when a task is given to a subject which requires some degree of expectant attention, CNV is present and is usually of greater amplitude when the subject must be actively attentive (Hillyard, 1974).

When subjects were required to detect a barely audible S2 (Low, Coats, Rettig, and McSherry, 1967; Rebert, et al., 1967), CNV was significantly elevated. As the difficulty of the task increased (by making S2 more difficult to detect) and greater attention to the S1-S2 was required, the CNV was of greater amplitude. Wilkinson and Haines (1970) showed that increased CNV amplitude during vigilance was associated with percent detections. CNV was also enhanced in situations in which response requirements presumably heightened attention to S2, such as when a motor response to it occurred, while none occurred in a control situation (Straumanis, Shagass, and Overton, 1969), when the motor response to S2 was instrumental compared to when it had no effect (Peters, Knott, Miller, Van Veen, and Cohen, 1970), and when reaction time was fast (Connor and Lang, 1969; Lacey and Lacey, 1970; Loveless, 1973; Rebert and Sperry, 1973). Contrary to these results, a number of studies have shown no relationship between attentive behaviour and the CNV. With extensive practise in the S1-S2 task, reaction time can be maintained at the same level while CNVs decline (McCallum, 1969). Further dissociation include a report that near total absence of CNV following sleep loss did not necessarily retard reaction times (Naitoh, Johnson, and Lubin, 1971). In a multichannel recording session, Papakostopolous and Fenelon (1975) showed significant correlation between reaction time and CNV over posterior sites but no correlation anteriorly.

Another means of manipulating attention has been through distraction paradigms: disrupting the expectation period between S1 and S2. Endogenous distractions such as daydreaming (Rousseau, Bostem, and Dongier, 1968) and full bladder (McCallum, 1967) and exogenous distractions such as reading, music, or conversation (McCallum and Walter, 1968; Walter, et al., 1967) or irrelevant noise occurring between S1 and S2 (Walter, 1968) have been shown to reduce CNV. In a more systematic study, Tecce and Scheff (1969) interspersed four numbers or letters within the S1-S2 interval. The subject's task was to recall the order of the letters or numbers following a motor response to S2, therein diverting attention away from S2. CNV was significantly reduced during the distraction task. Moreover,its reduction could not have been due to decreased arousal since heart rate recordings suggested if anything increased arousal.

Many investigators have looked at the relationship of CNV and motivation. Irwin, Knott, McAdam, and Rebert (1966) paired a tone to the right ear with a strong shock. A larger CNV was present preceding strong shock than weak.

Requiring subjects to exert more pressure or effort in making the motor response to S2 increased the magnitude of CNV (Rebert, et al.

1967). Similar results interpreted as "intent to perform" were reported by Low and McSherry (1968). The readiness potential recorded prior to voluntary movement (Deecke, Scheid, and Kornhuber, 1969) may be a contaminant in these studies.

CNV has also been found to vary with task difficulty. In a signal detection task, Hillyard, Squires, Bauer, and Lindsay (1971) reported that the CNV is larger prior to correct detections. In a comparable task (McAdam and Rubin, 1971), subjects were asked to report detection of a letter by button pressing, and to rate the confidence of their decision. Following the task stimulus and prior to the button pressing, a slow readiness potential developed whose amplitude was in direct proportion to the confidence of the decision. Correct decisions were associated with greater potentials than incorrects. Wilkinson and Haines noted that CNV was positively correlated with correct decisions in a vigilance task.

Data presented by Delse, Marsh, and Thompson (1972) indicated that the sex of the subject must be taken into account. In a discrimination task, the CNV was largest with easy discriminations but for females only. Incorrect decisions were associated with greater CNV amplitude than corrects, contrary to Hillyard's findings. The results for males were inconclusive. Neither task difficulty nor outcome of decision affected CNV.

Another class of slow potentials are those that develop after S2 as if the subject were continuing to process more information. These waves are particularly frequent with schizophrenics (Timsit, Koninckx, Dargent, Fontaine, and Dongier, 1970) although they have been reported in normals (Weinberg, 1972, 1975) and seem to be related to feedback. Weinberg (1975) hypothesized that motivation played a role in persistence of these "post-imperative negative waves" (PINV) with an increased presence if being correct was important to the subject.

> ... after feedback, and incidentally also preceding feedback, there are "CNVs" which are generated corresponding to the 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)

Serious artifacts such as those arising from physiological contamitants, largely skin potentials and eye movement potential have played havoc with CNV recording. Karrer, Fabregat, Czaja, Kohn, and Ptashne (1971) pointed out that large vertex slow waves occurring at the same latency and time course as the CNV were seen under certain conditions, and thenonly on certain trials, those which "surprise" the subject. These slow "arousal" waves were not eliminated by scalp skin drilling beneath the electrodes, an indication to the authors that galvanic skin potentials were not their source. On the other hand, Picton and Hillyard (1972) have obtained direct evidence that these potential shifts are in fact of electrodermal origin. Scratching the skin under the mastoid reference electrodes (Karrer et al.

scratched at scalp sites) until blood appeared almost completely abolished the vertex-negative shifts, indicating that they actually represent mastoid-positive skin phenomena.

The most well-documented contamination of the CNV results from slow rotation of the ocular dipoles, often in synchrony with the behavioural task. The electric fields of these dipoles are distributed across the entire scalp to the extent that eye rotations can engender potential shifts at the vertex larger in amplitude than the CNV. Early reports indicated that CNV was not related to eye artifact and was entirely cerebral in origin (Cohen et al., 1965; Walter, 1965). Hillyard and Galambos (1970) later presented evidence demonstrating that about 25% of the CNV at the vertex could be accounted for by eye movement. Eyeblinks may cause similar effects. Similar high correlations between CNV and vertical eye movement have been reported by Straumanis et al. (1969) and Wasman, Morehead, Lee and Rowland (1970). The artifactual effect follows an anterior-posterior gradient (Hillyard and Galambos, 1970) and exists even as far posterior as the occiput (Rowland, 1968). Thus, while CNV occurs in the absence of eye movements, it can easily be affected by ocular potentials. Thus, "the sensitivity of CNV recordings to distortion by eye movements suggests that presentation of averaged CNVs be accompanied by averaged EOGs" (Tecce, 1972, p.94).

Because of the different types of slow waves, activity from various cortical locations have been recorded in relation to a number of behavioural tasks. Walter (1968) originally believed that the CNV represented a composite electrical potential based on frontal areas of the brain. More recently, reaction time paradigms have typically found CNV amplitude maximum at the vertex and somewhat smaller in frontal areas and smallest in posterior regions (Cohen, 1969; Gullickson, 1970; Poon, Thompson, and Williams, 1974). The early findings of a frontal dominant CNV (Low et al., 1966; Walter et al., 1964) have been attributed to spurious eye movements (Hillyard and Galambos, 1970; Vaughan, 1969a).

The vertex maximum CNV and its role with the motor response has been discussed by Donchin, Otto, Gerbrandt, and Pribram (1971) with monkeys and Otto and Leifer (1972) with humans. A frontal or central dominant CNV could be produced depending on whether the subject's response was to release a key or to press it in a reaction time situation. In his signal detection task, Hillyard et al's, (1971) distributions indicated that CNV was clearly anterior approximately equal at frontal and central locations and half amplitude parietally. Jarvilehto and Frustorfer (1970) have noted, on the basis of information gathered prior to voluntary movement in a discrimination task, that the CNV also was a frontal-central potential which is a combination of a central dominant readiness potential as a correlate of readiness to perform a motor response and a frontal dominant potential which is a correlate of subjective uncertainty.

The Late Positive Component (LPC), P3

The vertex potential of the averaged evoked potential was described as being dependent on a number of stimulus bound manipulations. A long positive wave, designated as the "late positive component" or P300 (because its latency is approximately 300 ms after stimulus onset), or more commonly, P3 (because it is the third positive peak), appears to be independent of the sensory modality or qualities of the stimulus which delivers the information (Sutton, Braren, and Zubin, and John, 1965). Rather a complex set of psychological variables have been manipulated effecting changes in the P3 wave. One of the most frequently researched paradigms has been a procedure in which the subject is asked to detect an occasional stimulus change.

Ritter and Vaughan (1969), on the basis of results obtained in an earlier short-term habituation study (Ritter et al., 1968) employed a design similar to that used in the Haider et al. (1964) vigilance task. For detected stimulus changes only, Ritter and Vaughan found a late positive component (LPC) with a latency ranging from 300 to 550 ms. They hypothesized that the LPC is an index of central processes involved in "cognitive evaluation" of mismatch between signal and nonsignal. The LPC was not interpreted to reflect the occurrence of a mismatch itself since when the task was made more difficult by reducing the difference between signal and nonsignal, they still found an LPC in response to both types of stimuli.

In the Sheatz and Chapman (1969) study, not only did the relevant comparison stimulus evoke a large amplitude P2 wave, it also evoked a later, large amplitude P3. P3 was interpreted to be a correlate of problem solving. Naatanen's (1967) criticisms however must be taken into account. The order of the relevant and irrelevant stimuli was fixed as was the rate of presentation. In addition, the perceptual decision always had to be made after the second of the relevant stimuli, creating a preparatory state of arousal.

Donchin and Cohen (1967, 1969) randomly alternated two figures at an average rate of once every 3-4 seconds. Superimposed on the alternating figures was a square flash of light at the average rate of 2-3 seconds. In one condition, subjects had to respond to the flashes by pressing a switch as fast as possible and in another to press the switch each time the figures alternated and ignore the flashes. The results indicated that the LPC developed when the eliciting stimulus was task relevant. Unfortunately, the data are tainted by the predictability of the stimuli thereby setting up a preparatory state, a criticism that led Donchin and Smith (1970) to carry out a replication of this study, the results of which will be discussed later in the chapter.

Smith, Donchin, Cohen, and Starr (1970) binaurally presented signal and nonsignal stimuli at fairly slow rates. The subject's task was to report the occurrence of the signal in a particular (attended) ear. An enhancement of P3 was noted when clicks acted as signals but not letters. Moreover, no differences were found between the attended and non-attended ear, likely due to the slow rate of presentation of the stimuli. The authors failure to find significance was attributed as being a function of the inexactitude of stimulus onset, hence time "jitter" averaging may have obscured the effects.

Hirsh (1971) extended the analysis time of an earlier Davis (1964) work, from 375 to 600 ms to allow for the inclusion of the LPC. Thirteen out of the sixteen subjects showed some degree of a P3 when a discrimination between two stimuli was required. Again preparatory readiness may have obscured the data.

Karlin, Martz, and Mordkoff (1970) and Karlin, Martz, Brauth, and Mordkoff (1971) carried out a follow-up of a Wilkinson and Morlock (1967) study that indicated that the amplitude of P3 increased with faster reaction times. In the Karlin et al. studies, the subject was presented with two stimuli a high and low pitched tone. In one condition (simple response), the task was to respond as fast as possible to all stimuli; in another (choice response), to respond as fast as possible to one stimulus, but to withold a response for the other. P3's were largest in the choice response condition, with no-response stimuli producing greater enhancement than the response stimuli. In the simple response condition, a comparison among individual subjects indicated that those who responded most rapidly were also those with the largest LPCs. The authors thus concluded that degree of involvement or amount of effort expanded was responsible for the P3 effects.

Harter and Salmon (1970) also presented either relevant or irrelevant stimuli. Averaged visual evoked responses from the occiput region showed a consistent increased positivity whose latency ranged from 290-340 ms when the relevant stimulus was attended. A two-stage model of information processing was favoured, the first stage consisting of a coding of afferent impulses due to a predisposition or set of the peripheral nervous sytem, being mediated by the primary projection areas and reflected in the early components of the evoked potential, while the second stage consists of the interpretation and evaluation of the sensory information, being mediated by the cortical association areas and reflected in the late activity of the evoked potential.

An interpretation resembling Harter and Salmon's has been provided by Picton and Hillyard (1974) and Picton, Hillyard, and Galambos (in press). They have adapted Broadbent's (1971) fundamental modes of stimulus selection, "stimulus set" and "response set", to their findings. Stimulus set attention operates by selectively blocking or attenuating some sensory channels more than others. The response set modes operate after the attenuator and involves the serial comparison of analyzed stimulus patterns against a set of memory representations. Sensory information is attended to on the basis of its matching internal stimulus templates which are generated in advance according to the subject's expectancy or confidence.

Further evidence of the endogenous nature of the P3 is furnished when the target stimulus to be detected is an occasional omission of a stimulus from a repetitive train (Barlow, 1969; Klinke, Fruhstorfer, and Finkenzeller, 1968; Picton, Hillyard, and Galambos, 1974a; Ruchkin, Sutton, and Tueting, 1975; Weinberg et al., 1970, 1974). Detection of the omitted stimulus evokes a positive wave approximately 300-500 ms after the stimulus had been expected to occur.

Signal detection paradigms have emphatically pointed to the importance of actually detecting the signal. Growing out of the controversy surrounding the issue of the relationship between a threshold level stimulus and the subsequent evoked response, Hillyard (1969) and Hillyard et al. (1971) attempted to resolve the conflict by taking the subject's response bias into account. P3 was evoked on hit trials only and not for false alarms. It (P3) increased with increasing sensitivity. When the subject's decision criterion was taken into account by manipulations of a payoff matrix (Paul and Sutton, 1972) or by asking the subject to rate the confidence of each decision (Squires, Hillyard and Lindsay, 1973b; Squires, K., Squires and Hillyard, 1975), P3 was noted to increase in amplitude or area with increasing criterion. Similar results were found when the _a priori_ probability of the occurrence of the signal was set at 0.2, 0.5, or 0.8 (Squires, K. et al., 1975), which is consistent with the Hillyard et al. (1971) proposal that P3 is governed by the confidence of a detection, since those signals which elicit "sensory magnitudes" (Green and Swets,

1966) great enough to exceed an elevated criterion level are detected with greater certainty than those that exceed a less strict criterion.

False alarm trials did elicit P3 components in the Squires et al. (1973b, 1975) studies, which were larger in amplitude than those associated with either correct rejections or misses but much smaller than hit trials. Cael, Nash, and Singer (1974), however, reported significant P3 waves for these other elements in the signal detection matrix. They suggested that the LPC was an index of the resolution of uncertainty and not simply a correlate of a "detect" response. There is some question of this data, however, because of possible CNV falloff coming at about the same time as any possible P3,and therefore confounding the results.

A current concern among the evoked potential researchers is the role played by variations in the subjects' level of attention. The forementioned studies assumed active attention was a prerequisite to obtaining a P3 wave. Indeed several studies have shown that ignoring the target resulted in an absence or at best a significant diminution of P3 (Picton and Hillyard, 1974; Squires et al., 1973b; Wilkinson and Morlock, 1967). Further work, however, has uncovered a long latency positive peak, also designated P3, evoked in situations in which the quality of the signal itself draws the attention of the subject, who is passively engaged in an unrelated task such as reading (Ritter et al., 1968). Roth and Kopell (1973) had subjects engage in a distracting manual dexterity task but nevertheless found substantial P3s to unpredictable changes in stimuli. Roth (1973) instructed subjects to ignore all stimuli as much as possible. In a train of frequent tone bursts, he placed an infrequent unexpected noise burst according to a high, medium, or low probability schedule. The amplitude of the LPC was largest for the low probability and smallest for the high probability conditions. The latency of the LPC, at 217 ms, was uncommonly earlier than in other reports. Roth's interpretation of his data complied with that of Ritter et al. (1968) -- P3 being a component of the orienting response rather than a decision process.

Squires, N., Squires, and Hillyard (1975) questioned the use of the appellation, P3, for a component that not only was evoked during conceptually disparate situations of active versus passive attention, but also differed in latency of occurrence, ranging from 217 ms (Roth, 1973) to 550 ms (Ritter and Vaughan, 1969). Their solution was to distinguish between the signal detection P3 and the orienting response P3 on the basis of response latency and scalp topography. Using factor analytic techniques, they identified an early, low voltage positive peak, P3a, (latency about 240 ms), which was elicited by infrequent, unpredictable shifts of either intensity (Ritter et al., 1968) ; Picton and Hillyard, 1974) or frequency (Wilkinson and Lee, 1972), in a train of tone pips whether the subject was ignoring (reading a book) or attending the tones (counting). A still latter positive peak, P3b (mean latency about 350 ms) occurred only when the subject was actively attentive. P3a was largest in the frontal-central regions while P3b was more central-parietal. Because P3a occurred in both attend and ignore conditions and had a distinctive cortical location, it appeared to represent psychophysiological events quite different from P3b.

> The fact that P3a can be elicited by loudness decrements as well as by increments and pitch changes suggests, rather, than this wave reflects 'mismatch' to an ongoing stimulus train, whether or not it is attended. In this interpretation, P3a 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. (p.400)

Recent data from Roth's laboratory (Ford, Roth, and Kopell, 1976) replicated a number of these findings. The degree to which an irregular target tone pip differed in frequency from a standard, ranged from 100 to 25 to 5 per cent. The subjects either responded each time a mismatch was heard or read a book. Under both attend and ignore conditions, P3 increased with increasing changes in the target signal. The passive P3 was much smaller in amplitude and shorter in latency (mean = 295 ms) than the active P3 (mean latency = 330 ms). Unlike the Squires, N. et al. P3a, the Ford et al. passive P3 showed a uniform scalp distribution. The active P3 in both instances was maximally distributed over the central-parietal regions. The data was interpreted as reflecting two stages of the orienting response: the first, representing the degree of significance of events, i.e., a neural correlate of the human orienting response and the later an "additional overlay of attention" adding to the orienting response as an index of confidence that a significant event did indeed occur. In this manner, the interpretation of the signal detection data (Hillyard et al., 1971; Squires, et al., 1973b) seems analagous.

To add to the variety of types of late positive waves, just published experimentation by Courchesne, Hillyard, and Galambos (1975) again pointed to two types of P3s, one being frontal, the other parietal. The Courchesne frontal P3 differs from Squires, N., P3a and Ford's passive P3. Visual evoked potentials were recorded from subjects performing a visual discrimination task. Subjects counted an infrequent numerical stimulus (4) occurring in a frequently occurring numerical (2) background. Intrusive, task irrelevant (not counted) stimuli were also interspersed rarely and randomly, these stimuli being of two types: "simples" which were easily recognizable (geometric figures, words) and "novels" which were completely unrecognizable (complex, abstract colours). The counted 4's and simples evoked large, posterior P3 components while the novels evoked large, frontal P3's. In a control condition, when a novel stimulus became familiar in content and predictable in time of delivery, it evoked only small and posterior P3's similar to those elicited by the irrelevant easily recognizable simple stimuli. Thus P3 frontally is not a response to stimulus complexity but instead is dependent upon the stimulus being unrecognizable and unpredictable, i.e., a true novel stimulus in the Pavlov-Sokolovian context. While Ritter et al. (1968), Fruhstorfer and Bergstrom (1969) and Frustorfer (1971) have as well proposed an orienting response role for P3, their rare and unpredictable stimuli evoked large posterior LPCs, while little activity was obtained frontally. It is apparent though, that their easily coded stimuli are comparable to Courchesne's "counted 4's" or "simples" but very different from the highly unrecognizable "novels".

Another recent extensive report (Hillyard, Couchesne, Krausz, and Picton, 1975) examined the topography of P3s obtained in a variety of experimental designs in an attempt to verify the proposition that P3 is a unitary physiological entity. Their conditions were essentially replications of previous work but with special consideration paid to scalp distribution. In a "go, no-go" experiment, the no-go (response witheld to a particular stimulus) P3 was situated more anterior than the P3 obtained in threshold or omitted stimulus experiments. The similarity of the omitted stimulus and threshold type signal P3s provides a strong basis for proposing that they represent identical brain events, associated with the detection of specific target signals among a set of non-signals.

In brief, a substantial volume of literature exists purporting to describe the effects of a detection of an infrequent target signal occurring in a background of frequent, regular stimuli. Interpretations of the data have been founded on whether the subject was attentive or not, whether the target was detected or not, and on the latency and topography of the subsequently evoked LPC. Generally, Squires, N., et al's. (1975) P3b had a waveshape, topography, and latency in accord with the P3 peak observed by Ritter et al., (1968) which served as an index of the orienting response, as well as the P3 observed in hit decisions in a series of signal detection studies (e.g., Paul and Sutton, 1972; Squires et al., 1973b). The target may in fact be an omitted stimulus (e.g., Picton et al., 1974a; Simson et al., 1976; Weinberg et al., 1974) or the more frequently employed, actual change in stimulus or stimulus quality. An assortment of frontal dominant P3 components have also recently been defined, varying from an orienting type response during nonattentive states resulting in a short latency, low amplitude P3a (Squires, N. et al., 1975) to one evoked by a completely novel, unexpected stimulus, resulting in a long latency, large amplitude peak (Courchesne et al., 1975) and finally to one evoked by a "no-go" type stimulus (Hillyard et al., 1975). The definite distinction between the frontal and parietal P3, in combination with the fact that the frontal P3 is elicited by a number of seemingly disparate psychological conditions, makes it doubtful that all types of P3s fall under the rubric of "target recognition" as Squires et al. (1973b) have proposed.

Target P3 Latency Most reports place the latency of the P3 wave within 300-400 ms post-stimulus. As mentioned previously, the P3, elicited by a stimulus change while the subject is in a non-attentive state, has raised some controversy. Ritter et al. (1968) reported a mean latency of 350 ms, Roth and Kopell (1973), 300 ms, Ford et al. (1976), 277 ms, Fruhstorfer and Bergstrom (1969), 230-240 ms, Squires, N. et al., (1975), 240 ms, and Roth (1973), 217 ms. Ritter et al. (1968) observed their P3 to be maximum at parietal sites, thus perhaps explaining their longer latency.

With respect to the parietal P3, it appears that a positive correlation exists between confidence of a decision and latency of P3, the more confident the decision, the shorter the latency of P3. Squires et al. (1973b) reported a shift of 80 ms between "signal present" decisions of high and low confidence. Ritter, Simson and Vaughan (1972) noted that latency of P3 was associated with decision (reaction time) latency in a difficult discrimination task. Posner, Klein, Summers, and Buggie (1973) similarly reported that longer P3 latencies accompanied perceptual decisions that entailed longer reaction times. Picton et al. (1974a) also indicated similar results, their decision attached to an omitted stimulus. In the Courchesne et al. (1975) study, simple, unexpected, irrelevant stimuli evoked P3s with latencies significantly longer than those evoked by the attended stimuli.

Topography With the exception of the orienting P3 or P3a, the large majority of studies have placed P3 in the central-parietal regions. Hillyard et al. (1975), Picton and Hillyard (1974), Simson et al. (1976) and Vaughan and Ritter (1970) have established P3 to be very widespread across the posterior and lateral scalp. With auditory stimuli, P3 amplitude was 50 per cent of its maximum amplitude at temporal and occipital sites, in contrast to P2 which was reduced to 16-21 per cent at these areas (Picton and Hillyard, 1974). Thus the major contributor of the LPC which often appears as a superimposition of a small delayed P2 and a large P3 is in fact P3. P2 like N1, is maximum at anterior sites. With visual stimuli, both P2 and P3 (evoked to an omitted stimulus) show occipital-parietal dominance, P2 being slightly larger than P3 over frontal zones (Simson et al., 1976).

CNV and the Late Positive Component

A number of studies demonstrate a marked covariance between CNV and P3. The fact that CNV and P3 are often evoked by analagous experimentation lends support to this relationship. The dual covariation has led to two hypotheses about the possible relationship. Naatanen (1967, 1970) has proposed that the P3 is related to the degree of generalized preparatory activity rather than by processes evoked by the stimulus. The P3 peak is thus essentially a reflection of the CNV preceding the eliciting stimulus, i.e., a covariation of "expectancy".

Karlin (1970) and Wilkinson and Haines (1970) contend that if the stimulus is unpredictable (thus eliminінating "preparatory activity"), the subject must maintain some general level of alertness between signal stimuli in order to detect them. Upon occurrence of the signal, a "decrease in readiness or in alertness" may be reflected in a positive return to baseline or "falloff" after sufficient latency (300 ms). The "reactive change in readiness" hypothesis allows for the variable latency range (from 217 to 550 ms).

The latter type of falloff was demonstrated by Donchin and Smith (1970). In their experiment, the CNV developed during the 2 second interval between trials of a vigilance task only when a stimulus was predictable and relevant to the task. The CNV baseline return summed with the P3 wave, increasing P3 amplitude on task-relevant trials.

Naatanen (1970) used a similar design, alternating soft and loud clicks, and obtaining similar results. He found increased evoked potential amplitude to task relevant clicks as well as larger CNVs preceding the relevant click. Based on data from his research, Hartley (1970) also proposed a concomitant CNV-P3 relationship.

A large body of evidence, on the other hand, has demonstrated that the CNV and P3 can be dissociated. Donald and Goff (1971) found that P3 varied as a function of the relevance of the stimulus to the subject's task independently of the CNV. Donchin, Gerbrandt, Leifer and Tucker (1972) have reported that a late positive component varies as a function of the type of task required of the subject (motor, predictive, computational) while the CNV did not. In their signal detection task, Paul and Sutton were unable to support a relationship between the CNV and the extent of accuracy of the subject's decision, these findings going opposite to Hillyard et al's. (1971) earlier data. In the Hillyard et al. study there was a dissociation between P3 and the CNV in the case of correct rejections. CNV was present; P3 was not.

A just published manuscript (Poon, Thompson, and Marsh, 1976) reveals that as a task becomes more difficult, both P2 and P3 increase in amplitude while the CNV decreases -- an inverse relationship. Delse et al. (1972) have also indicated that CNV decreases with difficult discriminations whereas several authors report enhancement of P3 with increasingly stringent tasks.

Further differentiation between the CNV and P3 comes from scalp distribution studies. The CNV appears to be frontal-central maximum while P3 is central-parietal. In the cases in which P3 is frontal, the CNV likely is small if present at all, due to the inattentive state of the subject.

A multivariate analysis employing factor analytic and discriminant function techniques (Donchin, Tueting, Ritter, Kutas, and Heffley, 1975) has explored the question to its fullest extent yet. The presence or absence of a warning signal (hence presence or absence of preparatory readiness) failed to affect the amplitude of the LPC. In addition experimental manipulations of predictability affected the amplitude of the LPC but not the amplitude of the CNV. Finally the discriminant function analysis indicated that the LPC and CNV were significantly differentiated by scalp distribution. On the basis of failing to find any common variance shared by the two factors, the authors conclude: "The data are consistent with the hypothesis that the P300 component is an endongenous cortical component invoked by the information processing requirements of the subject's task rather than by pre-stimulus, diffuse, generalized preparatory activity" (p.459).

Feedback P3: A final category of stimuli which elicit notably large P3 waves are those that confirm or disconfirm a subject's prior guess, response, or perceptual judgement. Because the major emphasis of this thesis was a probe into the constructs associated with P3 evoked by feedback stimuli, particular detail will be placed on related literature.

Research of this nature germinated out of the instrumental work of Sutton, Braren, Zubin, and John (1965), generally credited with the "discovery" of P3. They presented pairs of stimuli, the first cueing stimulus informing the subject that either a sound or a light "test" stimulus would occur 3 to 5 seconds later. The subject guessed what modality the test stimulus would take in the interval between the cueing and test stimulus. In one condition the subject was informed what the test stimulus would be, and in another a guess was required. Two levels of probability were employed, one in which sound followed light 33 per cent of the time and light after sound 67 per cent, and the other in which the probabilities were equal. In the 50:50 condition, all subjects showed greater P3 enhancement during the guessing condition. In the 33:67 condition, subjects displayed greater amplitude to the lower probability test stimulus. Furthermore, wrong guesses evoked larger amplitude P3 peaks than correct ones.

In an extension of this study, Tueting, Sutton, and Zubin (1971) expanded the range of probabilities of the test stimulus. Again the subject either had to guess the nature of the test stimulus or was informed what it would be. The results revealed an inverse monotonic function between the probability of occurrence of the test stimulus and subsequent amplitude of the LPC, with the lowest probabilities evoking the largest amplitudes. As far as outcome of the subject's guess was concerned, for correct detections ("hits"), the amplitude of P3 varied indirectly with decreasing probability of occurence of the test stimulus. Thus the greater the a priori uncertainty, the greater the amplitude of P3 evoked by a correct "feedback" or test stimulus. For misses, the data were grossly similar. When the proportion of misses was low, the amplitude of P3 tended to increase. However, the overall number of errors was low, ranging from 10 to 30 per cent, thus making fine discriminations difficult. It was obvious, however, that misses evoked larger P3s than hits. The authors attributed this to be due to the low probability of being wrong. Disconfirming "feedback" was less frequent than confirming. It was thus suggested that "unexpectedness" might be the primary correlate of P3. Friedman, Hakerem, Sutton, and Fleiss (1973) replicated the study finding essentially the same results. Moreover an examination of the CNV occurring between the cueing and test stimulus did not indicate an association with the P3 evoked by the test stimulus (Tueting and Sutton, 1973).

Nielson, Teas, and Izikowski (1970) employed feedback that was based on actual perceptual performance rather than the guessing game of Sutton and Tueting. The subject's task was to bisect a 2 second interval, the range of deviation (window) from the midpoint becoming increasingly narrower over the various conditions. AERs were measured to "correct" feedback stimuli only, the range of correctness varying from 34 to 64 per cent. With increasing stringency, the amplitude of "P2 (its latency suggests it is likely P3) — N2" (likely N3) showed a significant increase in amplitude. These results may again be interpreted with the Tueting unexpectedness hypothesis. With increasing stringency, correct feedback stimuli become rarer, hence the increase in P3 amplitude.

Benson and Teas (1972) in the same laboratory replicated the findings. As difficulty increased, P3 also increased. The range of error was relatively low, 7 to 42 per cent.

Employing a discrimination task, Picton and Low (1971) manipulated three levels of difficulty producing 27, 6 and 1 per cent error rate. The amplitude of the evoked potential (presumably N1-P3) evoked by "correct" feedback signals increased dramatically during the most difficult discrimination. CNV measures prior to feedback signals covaried with P3. The conclusion of P3 and CNV association was not however accepted. Subjects who "gave up" during the most difficult discrimination displayed large evoked potentials but little prior feedback negativity.

Jenness (1972a, 1972b) also used a sensory discrimination task but with a modified signal detection paradigm. A "task" click, one or the other of the discrimative stimuli, was sounded, the subject making the decision 1.6 seconds later and after another 2 seconds, the same click that had served as the task click was sounded again, if the discrimination had been correct. If the decision was incorrect, no feedback was provided. Thus in the signal detection matrix, "correct" feedback was provided for "hits" and "correct rejections", a 5¢ payoff awarded for the former and no payoff for the latter. A 5¢ loss was associated with "false alarms", and no loss for "misses". The correct detection rate varied from near chance to 80 per cent above chance. Because the feedback and task clicks were exactly the same stimulus, a means of investigating the effects of feedback versus a decision per se was established.

The feedback evoked late positive peak (a combined P2-P3) was two to four times larger than that for the task click. At low levels of accuracy, the AER elicited by the feedback stimulus did not differ from that elicited at high levels of accuracy, not supporting Tueting et al's. (1971) hypothesis. In a pilot study, "incorrect" feedback stimuli was provided. It evoked larger LPCs than the "correct" clicks, likely due to the fact that the subject was rarely wrong (from less than 50 per cent to 20 per cent of the times). Unfortunately Jenness opted not to carry on with the pilot research in his actual thesis.

No differences were found between feedback stimuli coded "hit" (+5¢) and stimuli coded "correct rejection" (no payoff). Payoff, therefore, had no effect on the amplitude of the LPC, contradictory to the data of Paul and Sutton (1972). Jenness concludes that salience or meaningfulness of the stimulus best resolve his findings.

In the Squires et al. (1973b) signal detection task, after the subject's decision had been made according to a confidence rating scale, coded signals confirmed or disconfirmed the subject's decision. Since the task was such as to allow for 75 per cent correct detection, disconfirming feedback occurred relatively infrequently. The amplitude and area of P3 was much larger for disconfirming than confirming feedback and the latency delayed with error, a finding either not often discussed by other research or not reproduced. The effect was attributed to the unexpectedness or unusualness of incorrect decisions, following Tueting et al's. (1971) probability effects. A somewhat different effect was found for the confidence ratings. For corrects only, a decreasing amplitude P3 wave was associated with increasing confidence. For incorrects on the other hand, regardless of the confidence of the decision, the resultant AER did not vary. A "ceiling effect" explanation was applied since the P3 to disconfirmation was of such large amplitude.

A two-stage operation was proposed. A template matching mechanism (Hillyard et al., 1971) is established to register the occurrence of each expected task-relevant signal. An output (P3) is proportional to the closeness of the match, thus the infrequent, unexpected disconfirming feedback evoking greater response than the frequent, expected confirming feedback. In addition, the output from the decision stage is added to a "bias" level that is set in advance according to the subject's expectancy (confidence) that a signal will occur. The effect of raising the bias level to the maximum is to limit the maximum effect of the LPC. Thus following a very confident discrimination, the subject has high expectations of receiving confirming feedback. As a result, the bias level is elevated such that only a small increment is possible before reaching the ceiling level (Squires, Hillyard, and Lindsay, 1973a).

Donchin, Kubovy, Kutas, Johnson, and Herning (1973) based a feedback procedure on the Sutton et al. (1965) prediction task. They modified the procedure by varying the degree to which the subject could utilize the information from preceding trials in predicting the outcome of future events. The subject was either informed of the patterned sequence or had to learn it during experimentation. One pattern was a simple alternating sequence, another, a more complicated pattern but still learnable and still another, a random, unlearnable sequence. The more unpredictable the pattern, the greater was the amplitude of P3 evoked by the "feedback" stimuli. The term, "general-purpose processor" was coined to explain the results. P3 reflects the activity of an intracortical processor which is invoked on demand by a host of data requirements, the more complex the processing the greater the amplitude of P3. It should be accentuated that Donchin and his co-workers do not consider P3 to be an output of the processing (Squires et al., 1973a) but rather the actual reflection of the degree of processing itself. No differences were found between confirming and disconfirming feedback.

In yet another pattern learning task, Poon et al. (1974) directly investigated informational processing demands. As in the Donchin et al. (1973) study, the subject had to learn a sequential pattern of flashing coloured lights. Subjects could, in addition, bet anywhere from 0 to 5 cents on each prediction. The first 30 trials served as an acquisition period during which time the pattern was learned, while the last 60 trials served as an overlearning period. The CNV prior to "feedback" was also measured. The data indicated that during acquisition, incorrect guesses (which occurred significantly less often than correct) evoked large amplitude P3 waves compared to correct. The LPC for the correct guesses was larger during the acquisition period than during overlearning which may be due to probability effects; subjects were correct less often during the acquisition trials. Topographically, the LPC was largest posteriorly declining significantly centrally and frontally. Hillyard et al. (1975) also found large parietal P3s evoked by confirming feedback stimuli. In the Poon et al. study, CNV was quite small, increasing in positivity from parietal to frontal regions. No correlation was found between it and P3 at any recording site. Monetary payoff had little effect, again opposite to Paul and Sutton's (1972) data.

The data was discussed in terms analagous to Donchin et al. (1973). The acquisition period required greater involvement with the stimuli as did incorrect guesses. Correct guesses in the overlearning period were less informative than during the acquisition period.

Other Components:

N2: At the same time that N1-P2 markedly decreases with decreasing alertness or arousal, N2 increases dramatically, this especially being the case with drowsiness and sleep (Osterhammel, Davis, Wier, and Hirsh, 1973; Williams and Tepas, 1962). Its scalp distribution like that of N1-P2 is fronto-central (Picton et al., 1974b).

Limited research has established some psychological correlates of N2. Haider et al. (1969) reported a negative wave with latencies between 250 and 350 ms linked with an orienting response to temporally aberrant clicks. Klinke et al. (1968) also found a prominent N2 wave to an unexpected shock. Similarly Squires, N., et al. (1975) demonstrated increases in N2 associated with decreases in probability of occurrence of the stimulus, while Courchesne et al. (1975) noted a large N2 peak

Table I

Summary of Feedback P3 Research

AUTHOR(S)	CONDITIONS	TASK	% ERROR	DECISION BASED ON	TYPE OF FEEDBACK	P3 MAGNITUDE	CNV
Sutton et al. (1965)	random occurrence of two stimuli Ratio of occurrence either 50:50 or 33:67	1) Guess next stimulus (certain condition) 2) S informed what stimulus will be (uncertain cond.)	max = 50%	guessing	Confirming & disconfirming	1) P3 larger with uncertain than with certain condition 2) in 33:66, largest with wrong guesses	not measured
Tueting et al. (1971)	Similar to Sutton et al., except range of probabilities extended, 20:80, 40:60, 60:40, 80:20	As in Sutton et al.	10 to 30%	guessing	Confirming & disconfirming	Large when prob. of an outcome was low. Larger with misses than with hits	No relation to P3 (Friedman et al., 1973)
Nielson et al. (1970)	Bisect midpoint of 2 sec interval	Correct interval becomes increasingly narrow	36 to 66%	sensory judgement	Confirming only	Increasing P3 with increasing stringency	not measured
Benson & Teas (1972)	Bisect midpoint of 2 sec interval	Correct interval becomes increasingly narrow	7 to 42%	sensory judgement	Confirming only	Increasing P3 with increasing stringency	not measured

Table I

Summary of Feedback P3 Research

AUTHOR(S)	CONDITIONS	TASK	% ERROR	DECISION BASED ON	TYPE OF FEEDBACK	P3 MAGNITUDE	CNV
icton & Low 1971)	Discrimination task	Three conditions in which standard & comparison gradually approach one another	1, 6, 27%	sensory judgement	Confirming only	Increases with most difficult discrimination	With increasing difficulty, increasing CNV
Jenness (1972)	Discrimination task	Over 8-10 sessions, error rate decreased	20 to 50%	sensory judgement	Confirming only	No diff [illegible] between low & high levels of accuracy	not measured
Squires et al. (1973b)	Signal detection paradigm	S rated confidence of decision on a 3 point scale	.max = 47%	sensory judgement	Confirming & disconfirming	Larger amp & area with disconfirmation. Linear relationship with correct decisions & decreasing confidence. No relationship with incorrect decisions & confidence	not measured
Donchin et al. (1973)	Learn sequential pattern of two stimuli	1) simple alternating pattern 2) more complex, but learnable 3) random, unlearnable	max = 50%	guessing-learning	Confirming & disconfirming	More complex patterns produce increase in P3	not measured
Poon et al. (1974)	Learn sequential pattern of two stimuli	1) acquisition period-pattern to be learned 2) overlearning period-pattern learned	1) max = 50% 2) near 0%	guessing-learning	Confirming & disconfirming	During 1) largest with disconfirmation. Larger during scquisition than overlearning	No relation to P3

with the completely novel stimuli. In both of the latter cases, attention was not a prerequisite of N2 occurrence. An extensive study of graded differences of mismatch (Ford et al., 1976) indicated that N2 increased dramatically with all changes in stimuli regardless of the degree of difference between the standard and "novel" stimuli.

With feedback and related studies, somewhat opposite data are reported. Tueting et al. (1971) and Friedman et al. (1973) have associated larger N2 amplitudes with higher probabilities of occurrence of specific signals. In the Jenness (1972a) study, the peak to peak component P2/N2 tended to a slight degree to show an opposite trend to N2/P3, stimuli associated with no payoff evoking greater enhancement than those with positive or negative payoffs. To what extent this may be due to a decreasing function of P2 is not certain.

One consistent problem encountered during the survey of the literature was a general lack of precision and rigor in defining behavioural events. In spite of the fact that many of the experimental procedures used and the potentials measured overlap, a wide range of terms have been coined to describe what might well be a common underlying mechanism. Indeed such loosely defined concepts as "salience", "uncertainty reduction", "bias level", and "general-purpose processor", make generalizations concerning experimental findings from different laboratories difficult at best.

An attempted solution to this problem will be the employment of well-defined, measureable concepts derived from information theory (Attneave, 1959). Selective information is a logarithmic measure of the improbability of the occurrence of an event or of a message in a given situation. The amount or degree of information contained in an event is measured in "bits". The value of a bit of selective information may be measured in terms of the number of binary questions an individual needs to ask in order to gain one bit of selective information. By way of illustration, consider the simple task of locating a target in an array of four possible targets, in which case two bits of selective information are required. Only two questions are required to solve the problem, (1) "Is it one of these two?", if not, (2) "Is it this one?". Thus each target or item carries two bits of information.

Quite recently Ruchkin and Sutton (in press) have utilized informational theory terminology to describe their behavioural events. Unfortunately they did not actually measure the information value of their stimuli, or what they called "equivocation", in bits. This is believed to be the first study to actually quantify the informational value of the behavioural event and relate it to latency and amplitude measures of the physiological response.

The review of the literature has presented the major issues related to this study. Particular attention was paid to the nature of the late positive component process or processes. Table 1 presents a summary of the feedback P3 research providing a synopsis of the types of experimental conditions employed and the results found.

As can be seen, the question of the nature of the P3 process is far from answered. This thesis presents a series of experiments designed to evaluate the possible psychological determinants of P3. One particular question was whether the P3 wave reflected the processing of information or the outcome of such processing. A test of such a question would involve the evaluation of whether disconfirming feedback differed from confirming feedback independent of the information content of the feedback stimuli. To examine this possibility, a time estimation task was used as a basic paradigm, since it allowed wide variation of stimulus probabilities as well as manipulation of amount of task relevant information content and incentive and value of the feedback stimuli.

Based on past research findings, certain manipulations of the independent variables were expected to differentially affect the various components of the evoked potential:

1. Component P3 has been shown to be larger in amplitude with disconfirming feedback than with confirming, hypothetically due to the increased cortical demands brought about by the former. In this study, regardless of the probability of occurrence of the respective feedback signals (and hence variation in task relevant information), disconfirmation was expected to evoke P3s that were larger in amplitude than those seen with confirmation.

2. Due to the demands of disconfirmation, the peak latency of P3 was expected to be prolonged compared to trials in which the decisions were confirmed.

3. Although the outcome of the decision was expected to account for a large portion of the variance in P3 amplitude, the residual may be explained by informational properties and to a lesser degree by incentive and value manipulations.

4. It is doubtful that the feedback response is a unitary cortical phenomenon. N1, for example, was expected to be posterior dominant since the feedback signal was in the visual modality. P3, however, should be much more widespread. P4, on the other hand, has been located in parietal zones. Soviet and American research have identified the frontal zones as being responsible for corrective behaviour. Thus, while P3 was expected to be largest parietally, the differences in amplitude between confirming and disconfirming feedback were expected at the frontal electrode location.

5. Components earlier than P3 were not expected to be altered by outcome of decision, in accord with previous research. This same expectation holds whether the actual feedback signal was relevant or not -- whether it actually informed the subject of the correctness of a previously made decision or not.

6. Because prior knowledge of post-stimulus events (occurrence of confirming or disconfirming feedback) was largely precluded, differential prepartion, as indicated by the amplitude of the pre-feedback CNV, was not expected to be altered. Because manipulations that affected the amplitude of the P3 component of the evoked potential were not expected to affect the CNV, the two should be statistically orthogonal.

7. With regard to the actual time estimation task, it was expected that error in estimation would significantly decrease when relevant feedback information was provided for the subject. Over time, as a "perceptual trace" or a "neural model" of the time interval developed, the error in time estimation was expected to decline, this being the case even when the feedback signal was completely irrelevant.

Statement of the actual hypotheses related to this study will not be made until the end of the second chapter, which describes in addition to the equipment and methodology, the specific conditions employed to answer the theoretical problems. Without an understanding of these specific conditions, a comprehension of the wide range of hypotheses cannot be made.

CHAPTER II

Methodology

The equipment and general procedure were designed to obtain and store behavioural and electrophysiological data during a time estimation task wherein feedback was given as to the accuracy of the response. The physiological data were monitored on-line as a means of verifying the recording and analysis procedure and were stored on magnetic tape for later retrieval and analysis. The behavioural data were recorded and analyzed on-line.

Subjects

Eight females, aged 21-25, served as subjects. All subjects participated in all experimental conditions, being paid a flat $10 rate for their co-operation. Psychological normality was assessed by the *Minnesota Multiphasic Personality Inventory* since some authors have reported association between evoked potentials and psychiatric disorders (Shagass, 1971; Timsit-Berthier et al., 1973), while a control on the level of intelligence was assumed by the fact that the subjects were either university students or graduates. Testing did not take place within one week of the menstrual period.

Experimental Paradigm

One of the basic objectives of this research was to investigate the determinants of the feedback evoked potential. Accordingly, experimental conditions were devised which manipulated the relevancy of the stimulus, its surprisal, the amount of task relevant information contained in the stimulus, value attached to a particular stimulus, and effects of incentive.

A time estimation task (Benson and Teas, 1972; Nielsen et al., 1970; Weinberg, 1974) was employed to alter the various conditions. Unlike the two-choice alternate guessing games (Sutton et al., 1965; Tueting et al., 1971) and signal detection tasks (Hillyard et al., 1971; Squires et al., 1973b) the stringency for correctness can be adjusted to generate error rates considerably higher than 50 per cent. Furthermore in the present context, feedback allows for corrective behaviour, comparing what was planned with what, in fact, took place. In this way there is a constant corrective principle providing for the liability of deviation from a given plan.

Each trial of a particular condition was presented according to a fixed time schedule in order to establish time locked evoked potentials. A trial began with a synchronization pulse which initiated a one second warning signal (WS). The offset (S1) signaled the start of a one second time estimation interval. The subject responded by pushing a button after the estimated period.

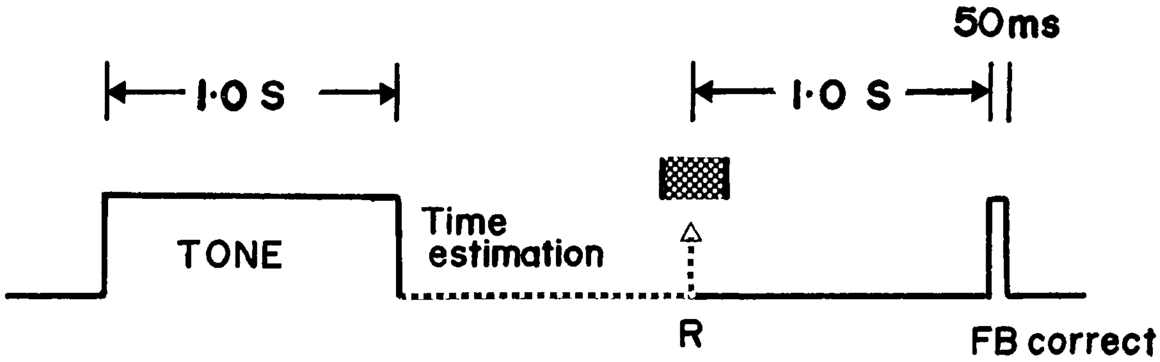
There were two basic conditions, an experimental, in which feedback was contingent on the subject's actual performance, and a control, in which feedback was based on a random pre-determined probability schedule (i.e., not contingent on performance). In the experimental trials, the experimenter defined a critical period (window) within which the estimation had to occur in order to be judged correct. A computer compared the time estimation with the window size. Feedback, in these trials, was either qualitative or quantitative. With qualitative feedback depending on whether the estimation fell inside ("correct" estimation) or outside ("incorrect" estimation) the window, one of two counters was activated at the time of the response, the same pulse starting the sweep of the evoked potential averaging period. With quantitative feedback depending on whether the subject had correctly estimated the interval, responded too fast ("underestimation") or too slow ("overestimation"), one of <u>three</u> channels was activated. In control conditions, before the start of the condition, the experimenter defined the probability of occurrence of each feedback stimulus. Hence at the time of response, regardless of its accuracy, one channel was randomly activated. One second after the response the computer relayed the appropriate signal to one or two or three light emitting diodes (LEDs) depending on the type of feedback employed in experimental sessions. The LEDs remained on for 50 ms. Figure 1 provides illustrated examples of the experimental procedure in four different conditions.

The independent variables were incorporated into the procedure in the following way:

A. Relevancy -- Feedback was either contingent on performance or based on a random probability schedule. In the former case, feedback is defined as task relevant; in the latter case, it is task irrelevant.

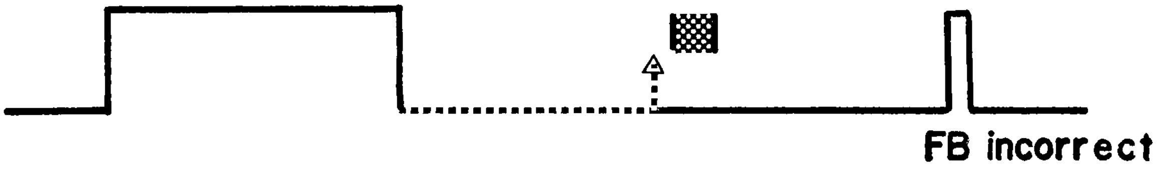
B. Surprisal -- Stringency for confirmation of the estimation was based on the width of the window. A wide window produced fewer errors

Figure 1. Schematic diagram of events in trial sequence. In A, the subject's response fell within the critical interval, feedback thus being coded, "correct." In B, when the window was narrowed, the subject responded too fast, thus receiving feedback coded, "underestimation." In C, using qualitative feedback, the same error (responding too fast) results in feedback coded "incorrect." In D, a control condition, even though the subject overestimated the interval, the "correct" LED was randomly flashed.



1· "Ideal" Response

2· Quant FB - Window narrowed



3· Qualitative FB

4· Random, Control

than a narrow window. Three window sizes were established, a narrow window in which the probability of confirmation was 0.25, a middle window in which the probability of confirmation was 0.50, and a wide window in which the probability of confirmation was 0.75. In the control condition, the probability of occurrence of the "correct" LED was 0.50. In cases in which quantitative feedback was employed, the probability of occurrence of either under or overestimation equalled half the probability of occurrence of disconfirmation, that is assuming subjects erred equally in both directions. For example, with the middle window, the probability of occurrence of confirmation to disconfirmation was 50:50, while the probabilities of confirmation to underestimation and overestimation was 50:25:25.

The amount of surprisal measured in "bits" defined according to informational theory procedure is:

$$S = \log_2 \frac{1}{p}$$

in which, S is the amount of surprisal

and, p the probability of occurrence of the feedback signal. Thus a signal that had a probability of occurrence of 0.25 contains 2.00 bits of surprising information (Attneave, 1959). Within each condition, "average uncertainty reduction" is equal to the sum of surprisals of all the alternatives (with quantitative feedback, the alternatives are "correct", "incorrect-under", and "incorrect-over") with each multiplied by its probability as a weighting factor.

The formula for average uncertainty reduction thus is:

$$H = \sum p_i \log_2 \frac{1}{p_i}$$

in which H is the average uncertainty reduction

and p_i the probability of occurrence of event i .

This is often called the Shannon-Wiener measure of information (Shannon and Weaver, 1949).

It is important that the rationale of the formula be understood -- it actually represents a properly weighted average (not a total, as the summation sign suggests) of the information involved in individual alternative events.

As an example, the probability of occurrence of confirmation, underestimation, and overestimation for the middle window condition was 0.50:0.25:0.25. Average uncertainty reduction therefore equalled,

$$H = \frac{1}{2}(\log_2 2) + \frac{1}{4}(\log_2 4) + \frac{1}{4}(\log_2 4)$$

$$H = \frac{1}{2}(1) + \frac{1}{4}(2) + \frac{1}{4}(2)$$

$$H = 2 \text{ bits}$$

C. Task relevant information: Surprisal was based on the probability of occurrence of an event. Thus a rare, unexpected random stimulus was more surprising than a more common task relevant feedback signal. The amount of task relevancy depends on two qualities:(a) the degree to which the feedback stimulus actually informed the subject of her past performance and (b) its surprisal. In informational terminology it is again defined as $\log_2 1/p$. In the cases of quantitative feedback, the amount of surprisal and task relevant information are equivalent. However, with control stimuli, there is a marked discrepancy -- surprisal being based strictly on probability and task relevant information equalling zero bits since no information was provided as to the accuracy of the time estimation. With qualitative feedback, in some conditions, two LEDs were employed to disconfirm estimations outside of the window while in others only one was employed. The calculation of the degree of task relevant information will be demonstrated with the aid of an example. Consider once more the case of the middle window, the probabilities of confirmation, underestimation, and overestimation being .50, .25, and .25. With quantitative feedback, the amount of surprisal was 1.00, 2.00, and 2.00 bits respectively, the amount of task relevant information also being 1.00, 2.00, and 2.00 bits respectively. If qualitative feedback were employed and one LED represented disconfirmation, the probabilities for confirmation versus disconfirmation would be .50 for both, the degree of surprisal and task relevant information in both cases being 1.00 bits. If two LEDs were employed for disconfirmation, changing the probabilities to .50, .25, and .25 once again (serving as a comparison with the quantitative feedback), the amount of surprisal returns to 1.00, 2.00, and 2.00 bits respectively. However, the amount of task relevant information is calculated on the former basis, thus the stimuli contain 1.00, 1.00, and 1.00 bits of task relevant information.

The average amount of task relevant information followed the same logic and was calculated with the identical formula as for average uncertainty reduction. In the case of qualitative feedback using two LEDs for disconfirmation the formula equals

$$p_c \log_2 \frac{1}{p_c} + p_d \log_2 \frac{1}{p_d}$$

where p_c is the probability of confirmation,
and p_d is the probability of disconfirmation overall.

Thus whether one or two LEDs were employed for disconfirmation, the average amount of task relevant information in a condition was the same.

D. Incentive: Three types of incentive were set up. In the negative incentive condition, a loss of 10 cents was attached to errors. No gain was given for correct estimations. In the positive incentive condition, the opposite was true, a 10 cent gain for correct estimations, but no loss for incorrects. A third condition combined the two, a 10 cent gain for corrects, and a 10 cent loss for incorrects. In a control no incentive condition, no payoffs were provided for either corrects or incorrects. Quantitative feedback was employed throughout this segment of the study.

E. Value: Two qualitative feedback conditions were run employing two LEDs in each instance for disconfirmation, the computer selecting the appropriate LED on a random equal probability basis. In one condition, the subjects were rewarded with a 10 cent gain for correct estimations, but a 10 cent loss was attached to either disconfirming LED. In a second condition, 10 cents was again provided for correct estimations. With incorrect estimations, however, a 20 cent loss was attached to one of the LEDs while no loss was attached to the other LED. Thus in the second condition a differential value scheme was established in association with particular stimuli. The incentive overall however remained constant, a 10 cent gain for corrects, and an average of 10 cents lost for incorrects.

Experimental Protocol

Testing took place over a three day period due to the large number of conditions. Each session lasted about 1½-2 hours. On the first day, subjects arrived at the laboratory approximately one hour prior to the commencement of actual experimentation.

The task was explained to the subject and then 50-75 practice trials were run. The window was first opened quite wide to allow the subject to become familiar with the procedure. It was then gradually reduced to a "threshold" point at which time the error rate was 50 per cent. The practice session served a number of purposes. For the subject, it served as a familiarization period for both task requirements and the laboratory situation. Moreover it established a setting from which the various stringency levels could be defined. The middle window was set 20 ms less than the threshold point of the practice runs. The narrow window was approximately 100 ms less than the middle while the wide window was 150 ms greater. The width of the various windows was therefore dependent on individual performance levels (establishment of middle window) and partially objective (narrow and wide windows). The middle window for most subjects was around 250-300 ms, although it was as low as 150 ms for one subject and as high as 350 for another. It should be noted that a window size of for example 200 ms, meant that the subject's time estimation had to be within 100 ms of the 1000 ms interval (i.e., 1000 ± 100 ms) to be judged correct.

A final purpose of the practice session was to teach the subjects control of extraneous movements, eyeblinks, and eye movements, which have been demonstrated to markedly affect evoked potentials (Hillyard and Galambos, 1970). Forehead muscle artifact (frontalis muscles) are particularly prominent with feedback stimuli. Eye movement was monitored during the practice session, the subject being informed if eye artifact had occurred during a trial -- the period from the initiation until one second after the offset of the feedback stimulus. Blinking and eye movement were permitted after this interval. The experimenter monitoring eye activity, waited until the eyes had fixated before initiating a trial. On actual runs, most subjects adopted a technique in which they fixated for long periods of time, rather than blinking after each trial, thereby considerably reducing the length of a session. On the second and third days, the practice sessions were eliminated. Before each condition on all three days, subjects were informed of the nature of the condition and the probability of being correct.

On Day 1, the effects of task relevance and surprisal were assessed. Four conditions were employed.

1. Narrow window: Using a narrow window, a correct to under to overestimation ratio of 25:37.5:37.5 was sought.

2. Middle window: As in condition 1, except the window was widened to allow a correct to under to overestimation ratio of 50:25:25.
3. Wide window: As in conditions 1 and 2, except the window was widened even more to attempt to obtain a ratio of 75:12.5:12.5.
4. Random, control: Feedback was not contingent on performance but rather was triggered by a computer generated probability schedule that flashed the three LEDs according to a 50:25:25 (middle window) ratio. The LED with the highest probability of occurrence occupied the same position as the "correct" LED in conditions 1-3.

A fairly involved counterbalancing order was instituted. Because of the small number of subjects, complete counterbalancing of order effects was impossible. However, the temporal order was such that each condition appeared twice in the first, second, third, and fourth positions. A system of counterbalancing and randomization was hence conjugated. The order of presentation of each condition for each subject is shown in Table 3. Positional effects for the LEDs was also controlled, each LED having an equal probability of representing correct, under, and overestimations. The same positions were maintained on Days 2 and 3, and are shown in Table 2 for each subject.

On Day 2, incentive and value were investigated. As mentioned previously there were four incentive conditions, (1) negative, (2) positive, (3) negative and positive, and (4) no incentive. Feedback was quantitative, the ratio of correct, under, and overestimation being equal at 0.33. Two conditions varying in value were run, one with a

Table 2

Counterbalancing of LED Positions for Individual Subjects

	LED1	LED2	LED3
Subject JBB	correct	over	under
Subject CSA	correct	under	over
Subject BS	correct	under	over
Subject MH	over	under	correct
Subject KA	under	correct	over
Subject MP	under	over	correct
Subject LC	under	over	correct
Subject DC	over	correct	under

Table 3

Randomization and Counterbalancing of Order of Conditions, Day 1

Subject	JBB	C	D	B	A
Subject	CSA	B	C	D	A
Subject	BS	A	C	D	B
Subject	MH	A	B	C	D
Subject	KA	B	A	C	D
Subject	MP	D	B	A	C
Subject	LC	C	D	A	B
Subject	DC	D	A	B	C

CODE:
A - Narrow Window
B - Middle Window
C - Wide Window
D - Random, Control

balanced matrix -- 10 cents gained for corrects, and 10 cents lost for error while a second was unbalanced -- 10 cents gained for corrects, but 20 cents lost when one of the LEDs coded "incorrect" was flashed and no loss when the other "incorrect" LED was flashed. With the value conditions, therefore, qualitative feedback was employed, the probability ratio of occurrence of any particular event being 0.33.

Due to the fact that the task was quite arduous, an additional $2.00 over and above the regular rate of pay was given at the beginning of Day 2, to which subjects could either add or lose depending on behavioural performance. The order of presentation for the six conditions for each subject is shown in Table 3a. Again as in Day 1, a combination of counterbalancing and randomization was employed.

On Day 3, the degree of task relevant information provided by the stimuli as well as surprisal were systematically investigated in detail. After pilot research with two subjects, it was noted that when the window was very narrow, the effects of confirming and disconfirming feedback were more or less equivalent. Because the amount of surprisal and task relevant information were the same, it was difficult to interpret these data. For this reason, the narrow window of Day 1, minus an additional 20 ms to allow for practice effects across the days, was employed across the various conditions of Day 3 to assess the task relevant information-surprisal differences. The following conditions were thus designed:

Table 3a

Randomization and Counterbalancing of Order of Conditions, Day 2

Subject JBB	D	A	B	F	C	G
Subject CSA	A	G	D	B	C	F
Subject BS	C	D	F	A	G	B
Subject MH	F	A	C	G	B	D
Subject KA	G	B	A	F	D	C
Subject MP	B	F	G	C	D	A
Subject LC	C	G	A	D	F	B
Subject DC	D	C	B	F	A	G

CODE:
A - Negative and Positive Incentive
B - Negative Incentive
C - Positive Incentive
D - No Incentive
F - Equal Value
G - Unequal Value

1. Quantitative feedback (QUAN): As in the narrow window of Day 1. Confirming, disconfirming-under, disconfirming-over feedback were utilized.
2. Qualitative feedback, high surprisal (QUAL-HI): Still employing the narrow window, feedback was qualitative rather than quantitative. Thus the subject's decision was either confirmed or disconfirmed. Two LEDs were employed for disconfirmation. The degree of surprisal then for the disconfirming stimuli remained the same as in Condition 1 (QUAN) but their degree of task relevant information decreased (see Table 5).
3. Qualitative, low surprisal (QUAL-LO): Similar to Condition 2 (QUAL-HI) except only one LED was employed to inform the subject of incorrect estimations. Thus the surprisal value for the disconfirming LED in the QUAL-LO condition was lower than for the QUAL-HI condition (Condition 2). The amount of task relevant information remained the same.
4. Control, high surprisal (CONT-HI): A control for Conditions 1 and 2. Three LEDs were flashed according to a 25: 37.5: 37.5 random computer probability schedule. The degree of surprisal of each of the stimuli was the same as for Conditions 1 and 2, the amount of task relevant information however equalling zero bits.
5. Control, low surprisal (CONT-LO): A control for Condition 3 (QUAL-LO), two LEDs being flashed according to a 25: 75 probability schedule. The degree of surprisal for each stimulus was thus equivalent in this condition and Condition 3.

In Conditions 3 (QUAL-LO) and 5 (CONT-LO) for half of the subjects, the position of the disconfirming LED was that of the underestimation diode of Condition 1 (QUAN), while for the other half it took the overestimation position. Counterbalancing and randomization of the order of presentation of the various conditions is shown in Table 4.

The degree of surprisal and task relevant information in each stimulus on each day is shown in Table 5. Also included is the average uncertainty reduction and average task relevancy for each condition.

Electrode Placement

The EEG was recorded from frontal, vertex, and parietal locations, using the International 10-20 System as a guide for placement (Jasper, 1958). Each day the head was measured from the nasion to the inion and from ear to ear using the preauricular points. The vertex electrode, Cz, was placed 50 per cent of the distance from the nasion to the inion and 50 per cent of the distance from ear to ear. The frontal electrode, Fz, and the parietal electrode, Pz, were also placed in the midline, 30 per cent and 70 per cent of the distance respectively from the nasion to the inion. All three electrode placements were monopolar with linked mastoids serving as reference. The subject was grounded by an electrode placed on the left arm.

One channel of data was used to monitor eye movement artifact. EOG activity was recorded between the supra- and infraorbital ridges.

Table 4

Randomization and Counterbalancing of Order of Conditions, Day 3

Subject JBB	C	A	B	E	D
Subject CSA	A	E	C	B	D
Subject BS	C	D	B	E	A
Subject MH	D	E	A	B	C
Subject KA	E	B	C	D	A
Subject MP	B	D	E	A	C
Subject LC	E	A	D	C	B
Subject DC	A	C	E	D	B

CODE: A- QUAN
B- QUAL-LO
C- QUAL-HI
D- CONT-LO
E- CONT-HI

Table 5

Coding, Probability of Occurrence, Degree of Surprisal, Amount of Task Relevant Information, Average Uncertainty Reduction, and Average Amount of Task Relevant Information for each of the Stimuli Over the Three Days of Experimentation

DAY 1	Narrow Window			Middle Window		
	LED 1	LED 2	LED 3	LED 1	LED 2	LED 3
CODE	Correct	Under	Over	Correct	Under	Over
PROB OF OCCUR	25%	37.5%	37.5%	50%	25%	25%
SURPRISAL	2.00	1.42	1.42	1.00	2.00	2.00
TASK REL INFO	2.00	1.42	1.42	1.00	2.00	2.00
AVG UNCER RED	1.56	1.56	1.56	1.50	1.50	1.50
AVG TASK REL.	1.56	1.56	1.56	1.50	1.50	1.50

	Wide Window			Random, Control		
	LED 1	LED 2	LED 3	LED 1	LED 2	LED 3
CODE	Correct	Under	Over	Irrelevant	Irrel	Irrel
PROB OF OCCUR	75%	12.5%	12.5%	50%	25%	25%
SURPRISAL	0.42	3.00	3.00	1.00	2.00	2.00
TASK REL INFO	0.42	3.00	3.00	--	--	--
AVG UNCER RED	1.06	1.06	1.06	1.50	1.50	1.50
AVG TASK REL	1.06	1.06	1.06	--	--	--

Table 5 (cont'd)

DAY 2	Neg & Pos Incen			Negative Incentive			Positive Incentive		
	LED 1	LED 2	LED 3	LED 1	LED 2	LED 3	LED 1	LED 2	LED 3
CODE	Correct	Under	Over	Correct	Under	Over	Correct	Under	Over
VALUE	+10¢	-10¢	-10¢	±0¢	-10¢	-10¢	+10¢	0¢	0¢
PROB OF OCCUR	33%	33%	33%	33%	33%	33%	33%	33%	33%
SURPRISAL	1.58	1.58	1.58	1.58	1.58	1.58	1.58	1.58	1.58
TASK REL INFO	1.58	1.58	1.58	1.58	1.58	1.58	1.58	1.58	1.58
AVG UNCER RED	1.58	1.58	1.58	1.58	1.58	1.58	1.58	1.58	1.58
AVG TASK REL	1.58	1.58	1.58	1.58	1.58	1.58	1.58	1.58	1.58

	No Incentive			Equal Value			Unequal Value **		
	LED 1	LED 2	LED 3	LED 1	LED 2	LED 3	LED 1	LED 2	LED 3
CODE	Correct	Under	Over	Correct	Incorr.	Incorr.	Correct	Incorr.	Incorr.
VALUE	0¢	0¢	0¢	+10¢	-10¢	-10¢	+10¢	-20¢	0¢
PROB OF OCCUR	33%	33%	33%	33%	33%	33%	33%	33%	33%
SURPRISAL	1.58	1.58	1.58	1.58	1.58	1.58	1.58	1.58	1.58
TASK REL INFO	1.58	1.58	1.58	1.58	0.60	0.60	1.58	0.60	0.60
AVG UNCER RED	1.58	1.58	1.58	1.58	1.58	1.58	1.58	1.58	1.58
AVG TASK REL	1.58	1.58	1.58	1.32	1.32	1.32	1.32	1.32	1.32

** For half of the subjects, LED 2 was associated with a 20¢ loss; for the other half it was LED 3.

Table 5 (cont'd)

DAY 3	QUAN			QUAL-HI			QUAL-LO (for 4 Subjs)		
	LED 1	LED 2	LED 3	LED 1	LED 2	LED 3	LED 1	LED 2	LED 3
CODE	Correct	Under	Over	Correct	Incorr	Incorr	Correct	Incorr	Not used
PROB OF OCCUR	25%	37.5%	37.5%	25%	37.5%	37.5%	25%	75%	0%
SURPRISAL	2.00	1.42	1.42	2.00	1.42	1.42	2.00	0.42	
TASK REL INFO	2.00	1.42	1.42	2.00	0.42	0.42	2.00	0.42	
AVG UNCER RED	1.56	1.56	1.56	1.56	1.56	1.56	0.82	0.82	
AVG TASK REL	1.56	1.56	1.56	0.82	0.82	0.82	0.82	0.82	

	QUAL-LO (4 Subjs)			CONT-HI			CONT-LO (4 Subjs)			CONT-LO (4 Subjs)		
	LED 1	LED 2	LED 3	LED 1	LED 2	LED 3	LED 1	LED 2	LED 3	LED 1	LED 2	LED 3
CODE	Corr	--	Incorr	Irrel	Irrel	Irrel	Irrel	Irrel	--	Irrel	--	Irrel
PROB OF OCCUR	25%		75%	25%	37.5%	37.5%	25%	75%		25%		75%
SURPRISAL	2.00		0.42	2.00	1.42	1.42	2.00	0.42		2.00		0.42
TASK REL INFO	2.00		0.42	--	--	--	--	--		--		--
AVG UNCER RED	0.82		0.82	1.56	1.56	1.56	0.82	0.82		0.82		0.82
AVG TASK REL	0.82		0.82	--	--	--	--	--		--		--

Six Beckman 16 mm diameter silver-silver chloride cup electrodes were attached to all locations except the orbital ridges, where the 11 mm Beckman silver-silver chloride electrodes were placed. The electrodes were filled with Beckman Offner paste. The skin was rubbed with acetone to remove grease and then scratched with a sterile needle until blood was drawn. The latter technique served to eliminate skin potential artifacts (Picton and Hillyard, 1972). The electrodes were attached with the appropriate adhesive collar either to gauze pads which had been cemented with collodion to the scalp or directly to the skin. The interelectrode impedance, measured at 10 Hz, was less than 1 KOhm for scalp-mastoid electrodes (mean = 0.82 KOhm, *S.D.* = 0.09), and less than 2.0 KOhms for the ground and EOG electrodes (mean = 1.46 KOhm, *S.D.* = 0.24).

EEG and EOG Amplification and Recording

EEG and EOG activities were amplified, recorded, and monitored on a Nihon-Kohden 8-channel multipurpose polygraph, model RM-85, equipped with an 8 channel oscilloscope, model VC-85. The three EEG channels were amplified 42dB on a.c. biophysical amplifiers, model RB-5 while the EOG channel was amplified 35dB, the amplifiers having been modified to have a time constant of 6.8 sec. The high frequency filters were set at 30 Hz. Such bandpass characteristics meant that slow changes (e.g., baseline shifts) in activity could be examined while such artifacts as 60 cycle noise filtered out.

The outputs of the four amplifiers were recorded on a Vetter 700 series model A 8-channel FM taperecorder at a recording speed of 3 3/4 inches (9.52 cm) per second. The synchronization pulses at the time of the subject's response representing the accuracy of the time estimation were recorded on three other channels and fed into three polygraph channels. 3M Scotch brand Pro-pack 206 1.5 mil high-output low-noise tapes were employed to store the data. The taperecorder channels were monitored on a Tektronix model RM 564 Storage Oscilloscope, equipped with two Tektronix Type 3A74 Four Trace amplifiers. On-line counting of the various feedback types was carried out by a three channel Lafayette data recorder, model 5804. Two channels of tape-recorded data were averaged on-line using a Nihon-Kohden averaging data processor model ATAC-201, in order to check on the proper functioning of the equipment.

Stimuli

The subject sat in an easy chair in a separate, dim, sound-attenuated chamber. At eye level 1.5 m directly in front of her was an 8 x 5 cm black box in which three red LEDs were mounted. The diodes, measuring 4 mm in diameter, were placed side by side in a horizontal line in the center of the box. The visual angle between the extreme left and extreme right LEDs was less than 5°. A response button was provided as a means of indicating the end of the 1 second estimate.

Timing, logic, and programming of the entire operation was effected by a PDP8e computer. The experimenter manually started a trial by pressing a key starting the computer's clock and logic. A pulse from the computer initiated a 1 second 500 Hz pure tone from a Hewlett-Packard 3300 A Function Generator furnished with a 3302A Trigger/Phase Lock mechanism. The computer registered the subject's response and stored it in memory. Depending on the condition, the appropriate synchronization pulse was relayed to the taperecorder, counter, and polygraph. One second later, a second 50 ms pulse in series with two 1.5V batteries flashed the respective LED on and off. Input, informing the computer of the logic of the condition, window size or probability schedule, and the number of LEDs to be utilized as feedback channels was carried out by teletype. The same teletype printed out the time estimations (in ms) for each trial at the end of a condition.

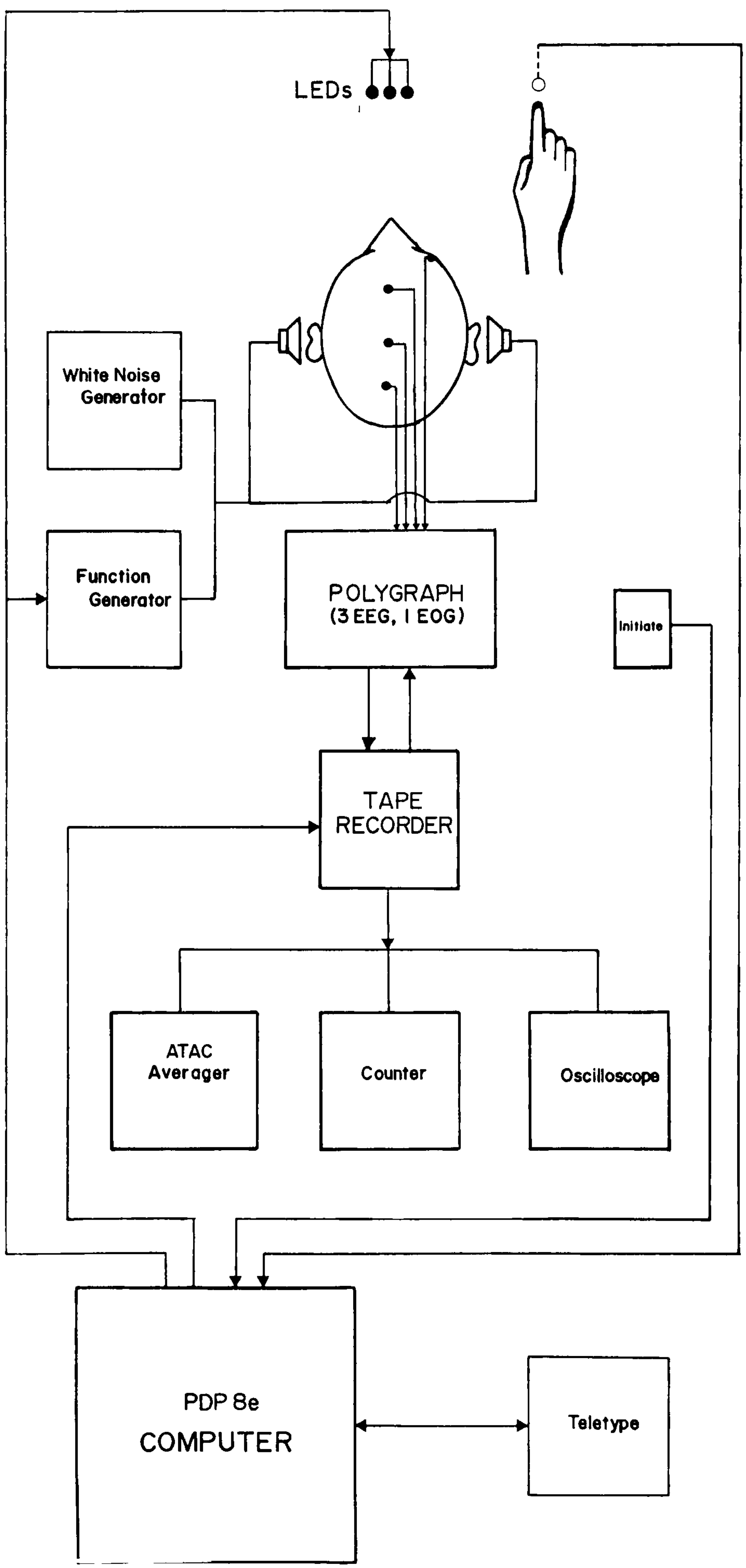
Auditory stimuli were heard by the subject through Symphonic headphones, model DH 288, over a background of white noise generated by a Lafayette white noise generator, model 15011.

Schematics for the stimuli presentations are presented in Figure 2.

Data Retrieval and Analysis

During the experimentation, two or three tape channels coded the synchronization pulses, representing either "correct," "underestimation", or "overestimation", this being the case regardless of the meaningfulness of the feedback. Trials in which eye movement, skin potential, or muscle artifact may have confounded the evoked potentials were eliminated after investigating the polygraph record.

Figure 2. Schematic diagram of equipment used for presentation of stimuli and collection of responses.


LEDs
White Noise Generator
Function Generator
POLYGRAPH (3 EEG, 1 EOG)
Initiate
TAPE RECORDER
ATAC Averager
Counter
Oscilloscope
PDP 8e COMPUTER
Teletype

Although data were recorded at a tape speed of 3 3/4 inches per second, retrieval time from a second Vetter taperecorder was at 15 inches (38.1 cm) per second. One of the channels carrying the synchronization pulses was connected to the trigger input of a Tracor Northern NS-575 A digital signal analyzer with an 8-channel input module NS-594-8. The trigger channel was also connected to a Tektronix DC 504 counter which added one "count" for each pulse exceeding a fixed amplitude (1.5V). Each type of feedback was averaged by manually selecting the non-contaminated trials. The final average for a specific feedback sequence within a specific condition consisted of 8 or a multiple of 8 trials. Two or usually three records, depending on the number of feedback pulses, were obtained for each condition for each subject.

EEG and EOG output from the taperecorder channels were conditioned by using Tektronix AM 502 differential amplifiers with unit gain and frequency bandpass 0-100 Hz. This enabled all outputs to be positively offset from 0 in order to match the input module of the signal averager. Four channel averaging (3 EEG and 1 EOG channels) was performed simultaneously over a 512 ms period (equivalent to 2048 ms real time).

The averaged data was plotted on a Hewlett-Packard XY recorder, model 7044A.

Calibration Techniques

Sound Levels Sound pressure levels were calibrated using a Bruel and Kjaer impulse precision sound level meter type 2204 with a type 4152 artificial ear coupler. The ambient room noise was between 50 and 60 dB SPL. The 1 second toneburst signal in the background of white noise measured 75 dB SPL, while the white noise alone was 60 dB SPL.

Stimulus Timing The timing for the stimulus presentations was measured using a Universal counter Racal 835 which was accurate to within 2µs over a 1 second sweep. Out pulses from the computer controlling onset and offset of the tone and LEDs were found to be accurate within 1 ms of the appropriate timing. LEDs were selected as stimuli because of their extremely rapid onset and offset, allowing for precise control over intensity. The error associated with the duration of the LED onset (50 ms) was less than 1 ms.

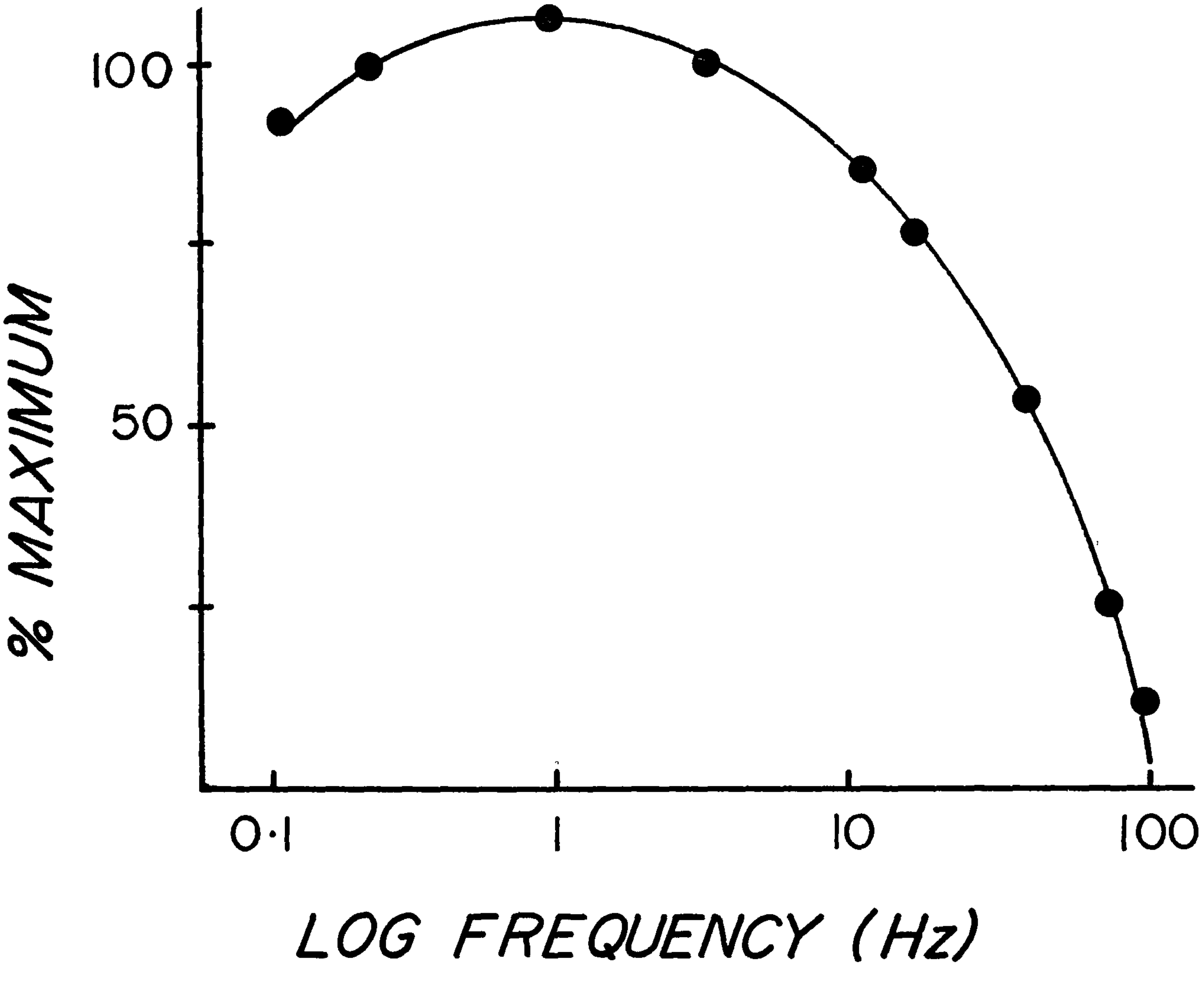
Amplitude Calibration Amplitudes of the evoked potentials were calibrated by recording a single trial of a known 200µV square wave through the four physiological channels of the polygraph, taperecorders, amplifiers, and signal analyzer. Prior to averaging, the individual channels of the taperecorder were adjusted to within 1 per cent of each other. Due to variations in the calibration and measurement techniques, any amplitude measurement is considered accurate to within 5 per cent.

Frequency Bandpass A frequency response curve of the amplification, taperecording, and signal analyses was computed by employing the Hewlett-Packard function generator and feeding known, constant voltage sine waves of varying frequencies into the polygraph input. The signal was then amplified, taperecorded, and played back into the signal averager, in all cases the exact same settings as for data analysis being used. The frequency response curve was determined by plotting the output from the signal averager with the original signal input. As can be seen in Figure 3, rolloff was particularly sharp after 8 Hz. Ninety per cent frequency limits of the whole system was 0.1 to 8 Hz.

Data Analysis

Since all evoked potential response waveforms possess multiphasic configurations, most investigators have somewhat arbitrarily selected prominent peaks and valleys applying measures of latency and amplitude as a means of quantitative analysis. More "objective" curve fitting techniques such as the Gaussian component technique (Lehman and Fender, 1968; Vaughan and Hull, 1963) or statistical techniques such as principal component factor analysis (Donchin, 1966, 1969) have been developed in an attempt to circumvent the subjective element in component identification. Unfortunately these techniques have not proven to be any more accurate than the human eye. In the words of Vaughan (1974), "Although it would be helpful to have some reliable procedural shortcut to the simple representation of the complex (evoked response) waveform, we are not justified in utilizing arbitrary criteria, since these resultant 'simplifications' may merely obscure the physiologically significant structure of the data" (p.184). In the present study, identification of the major peaks was carried out by hand following certain objective criteria.

Figure 3. Frequency response curve for the Nihon Kohden polygraph. Known, constant voltage sine waves of varying frequency were fed into the polygraph, then amplified, taperecorded, and played back into the signal averager, the output from the signal averager being the Y-axis, and the input signal being the X - axis.


100
50
% MAXIMUM
0·1
1
10
100
LOG FREQUENCY (Hz)

The method of amplitude measurement has also been a subject of wide discussion -- some components have been measured peak-to-peak, others baseline-to-peak. A peak-to-peak measurement assumes that the negative and positive portions of a response reflect a unitary neural process properly described by a single measurement. Both animal and human work have shown that manipulations affecting a negative peak may not necessarily affect the accompanying positive peak or vice versa. The neurophysiological evidence strongly suggests that a potential should be denoted as a base-to-peak change and measured accordingly (Goff, 1974).

Establishment of a baseline poses additional problems. Between the time of the subject's response (when the sweep began) and the onset of the feedback stimulus, slow baseline changes often occurred. Therefore the baseline was drawn through the arithmetic mean of the activity preceding the presentation of the feedback stimulus by 100 ms. The following measures were then taken as illustrated in Figure 4.

1. Pre-feedback CNV -- the average level of the waveform above or below the baseline in the period 350 - 450 ms after the subject's response (600-700 ms before feedback onset).

2. Feedback N1 amplitude -- the amplitude from baseline to the maximum negative peak occurring between 100 and 175 ms after the feedback tone onset.

3. Feedback P2 amplitude -- the amplitude from baseline to the maximum positive peak occurring between 160 and 275 ms after the feedback tone onset.

4. Feedback N2 amplitude -- the amplitude from baseline to the maximum negative peak occurring between 225 and 350 ms.

5. Feedback P3 amplitude -- the baseline to maximum positive peak measurement between 275 and 450 ms after the feedback onset.

6. Feedback N3 amplitude -- the amplitude from baseline to the maximum negative peak between 250 and 550 ms.

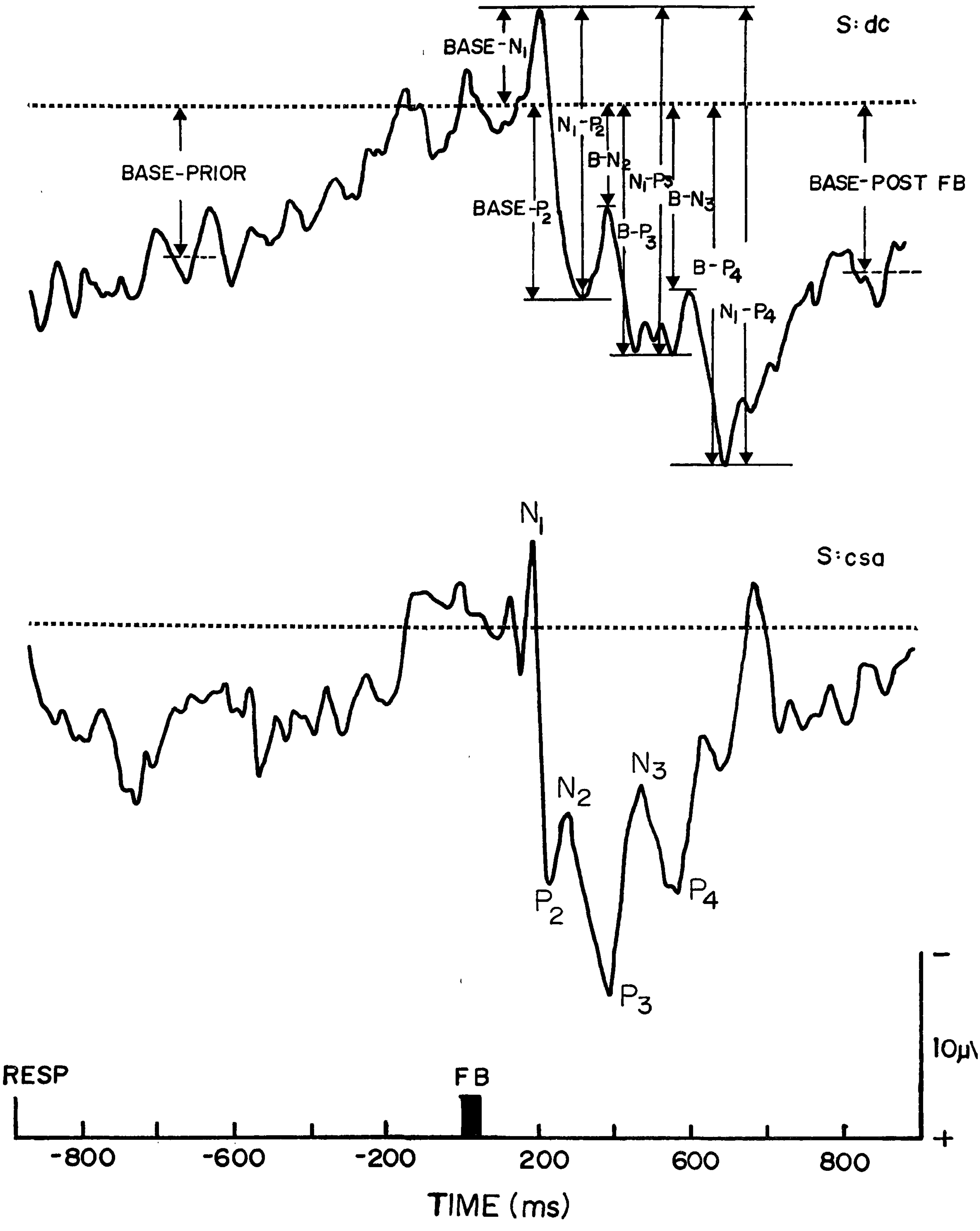
7. Feedback P4 amplitude -- the amplitude from baseline to the maximum positive peak between 450 and 650 ms after feedback onset.

8. Post feedback resolution -- the average level of the waveform above or below baseline in the last 200 ms of the waveform (800-1000 ms after feedback onset).

Two overall peak-to-peak measures, N1-P2 (Davis et al., 1966) and N1-P3 (Jenness, 1972a, 1972b; Ritter et al., 1968) were also taken. All amplitude measures were made at all three scalp locations, Fz, Cz, and Pz.

Latencies were measured at the peak of the various components, defined as the point of maximum deflection from the baseline. If the deflection remained flat at the peak, the typical latency for that subject was taken as the peak latency. This decision was however only rarely taken, usually in the cases of the P2 and N2 components. If a double peak was detected, the latency was taken as the mean between the two peaks. Initial analysis of latency measurements based on two subjects indicated a very close agreement across the three scalp locations. Latency measures were therefore taken only at the vertex location for the remainder of the subjects.

Figure 4. Waveforms from two subjects illustrating the measurement of the components of the evoked potential. Dotted lines represent baselines drawn to establish amplitudes for pre-feedback CNV and baseline-to-peak measures.


S: dc
BASE-N1
BASE-PRIOR
N1-P2
B-N2
N1-P3
B-N3
BASE-P2
B-P3
B-P4
N1-P4
BASE-POST FB
N1
S: csa
N2
N3
P2
P4
P3
RESP
FB
-800
-600
-200
200
600
800
TIME (ms)
10μ\
−
+

Finally, time estimates were tabulated for each subject on each trial on each condition. The computer provided a time estimate in milliseconds. The absolute deviation from 1000 ms was then calculated and averaged over the respective conditions to serve as an index of behavioural performance.

Statistical Analysis

The large number of conditions over the three days was separated into a series of experimental studies to be described later in this section. Within each experiment, various numbers of conditions were analyzed, each with at least two and more often with three types of feedback.

The amplitude of ten components of the evoked potential at three scalp locations and the latency of six components for one location were measured for eight subjects. A behavioural measure of the subject's time estimation was also calculated. Each subject was evaluated under all conditions, all feedback possibilities, and all scalp sites.

The rationale for the selection of appropriate statistical techniques is fully documented in another electrophysiological thesis (Stuss, 1976), with whom full collaboration was made in this phase of the study. A synopsis of the critical points will thus be presented.

Theoretically, the most suitable statistical procedure would involve some form of multivariate analysis. While it is true that the various components of the evoked potential constitute multiple dependent measures, there is ample evidence to suggest that each is an independent measure of some underlying neural event (Donchin et al., 1975; Squires, N., et al., 1975). Moreover the logistics of programming such a multivariate analysis of variance with at least three repeated measures is complex and appropriate computer programs are not readily available. Assuming such an analysis could be carried out, the interpretation of the immense output of data would necessarily present prodigious perplexities. The impracticability of such an approach led to the decision to apply univariate repeated measures analysis of variance for each of the dependent measures, with some necessary changes in the significance level to compensate for the fact that multiple tests were performed.

Another obstacle in the analysis was the wide range of experimental conditions, 15 in all over the three days. It was decided to largely make comparisons among only those conditions investigated on a particular day. Across day comparisons were limited for two reasons: (1) various uncontrollable factors such as adaptation to the laboratory situation, relaxation, and practice effects could have confounded the data and (2) the effects of the independent variables were not completely comparable across the days.

On Day 1, the effects of surprisal and degree of task relevant information on the behavioural measure, time estimation, and on the various physiological measures were examined. These analyses constituted what was referred to as Experiment 1-1. Three window sizes producing confirming feedback on 25, 50, and 75% of the trials were run. Three types of feedback signals were employed, informing the subject of either correct, under or overestimation. A fourth condition investigated the effects of irrelevant feedback -- the onset of the three stimuli being contingent on a random probability schedule rather than on actual accuracy of estimation. The three conditions in which feedback was relevant plus the one in which it was not, served as independent variables for a one-way repeated measures ANOVA comparison of the behavioural time estimations. A two-way repeated measures ANOVA (four conditions and three types of feedback) was used to analyze the physiological data. Hence in both analyses, window size served as an independent variable: A1, narrow window; A2, middle window; A3, wide window; A4, control; while the second independent variable was the type of feedback: B1, correct; B2, incorrect-under; B3, incorrect-over.

The results from Day 2 provided data for two other studies, termed Experiments 2-1 and 2-2. Experiment 2-1 examined the effects of incentive on the dependent measures. Conditions 1-5 from Day 1, served as the incentive variable, the levels being: A1, negative incentive; A2, positive incentive; A3, negative and positive incentive; A4, no incentive control; A5, no incentive, random incorrect control. Three types of coded feedback were employed: B1, correct; B2, incorrect-under; B3, incorrect-over. A one-way ANOVA with repeated measures on the A condition (incentive) was conducted when time estimation served as the dependent measure. When the physiological data were used, a two-way ANOVA with repeated measures on both the A (incentive) and B (types of feedback) was run.

Conditions 5 and 6 on Day 2 contained data for an extra study, Experiment 2-2 on value effects. In condition 5, a 10 cent loss was associated with both LEDs coded "incorrect", while in condition 6, a 20 cent loss was associated with one of the incorrect LEDs and no loss with the other incorrect diode. In both conditions a 10 cent gain was given for correct estimations. For the behavioural analysis, repeated measures on both independent variables, A1: balanced value (Condition 5) and A2: unbalanced value (Condition 6) were examined with a one-way ANOVA. The usual two-way conditions x feedback repeated measures ANOVA could not however be carried out on the physiological data since the payoff matrix in Conditions 5 and 6 was not equivalent. A one-way ANOVA with the six different payoffs serving as the repeated independent variables was therefore attempted, with two +10 cent, two -10 cent, one -20 cent and one 0 cent levels.

On Day 3, a further intensive investigation of surprisal and feedback task relevancy was conducted. The first study, Experiment 3-1, looked at the effects of the amount of task relevant feedback information on behavioural and physiologic measures, while holding surprisal constant. The behavioural comparison was thus a one-way ANOVA, the three levels of task relevant information serving as independent variables: A1, quantitative feedback (QUAN); A2, qualitative feedback (QUAL-HI, Condition 2 of Day 3), the surprisal value of the three feedback stimuli being the same as QUAN but the two disconfirming feedback containing less task relevant information than those of QUAN; A3, Control (CONT-HI, Condition 4), the surprisal value equivalent but the stimuli containing no task relevant information. As well as this independent variable, the three types of feedback stimuli served as a second independent variable. The three levels were: B1, correct; B2, incorrect-under, and B3, incorrect-over. In the case of qualitative feedback (QUAL-HI), "incorrect-under" and "incorrect-over" refer to the respective positions of the disconfirming LEDs and not to actual under or overestimation. Similarly with the control condition, the labels "correct", "incorrect-under", and "incorrect-over" are derived from the position of the respective LEDs.

Experiment 3-1 hence examined the role of task relevant information. Experiment 3-2 on the other hand studied both task relevant informational content of a particular stimulus and its surprisal. Condition 3 of Day 3 (QUAL-LO) employed only one LED to disconfirm estimations outside the window. Its degree of surprisal was less than for the disconfirming stimuli of either Condition 1 (QUAN) or Condition 2 (QUAL-HI), and task relevant informational content being the same as in QUAL-HI. A control condition was also run, CONT-LO, "disconfirmation" taking on the same degree of surprisal as the QUAL-LO condition. For the behavioural analysis the conditions making up the one-way repeated measures ANOVA were: A1, QUAN; A2, QUAL-HI; A3, QUAL-LO; A4, CONT-LO. With the physiological data a problem was apparent concerning the analysis of the types of feedback. In QUAN and QUAL-HI, three LEDs were employed, two for disconfirmation while with QUAL-LO, and CONT-LO, only one LED represented disconfirmation.

With the latter, for half the subjects the position of the disconfirming LED was that of the "incorrect-under" LED of Condition 1 (QUAN) while for the other half, it took the "incorrect-over" position. Hence it was decided to compare only the correct and one incorrect effect across the four conditions. With QUAN and QUAL-HI, the selection of the appropriate disconfirming LED followed the rationale for selection of the position of the disconfirming LED in QUAL-LO and CONT-LO -- for half the subjects "incorrect-under" was chosen, for the other half, "incorrect-over". Thus the two-way repeated measures consisted of the four conditions plus two levels of feedback: A1, correct; A2, incorrect.

In these five experiments, each component of the evoked potential was treated as a separate dependent variable based on the assumption that none co-vary (Donchin et al., 1975). To assess the validity of this assumption a correlational matrix (Pearson's "r") was computed for the entire set of physiological measures across all conditions, experiments, and days employing the data from the Cz location.

A day-to-day comparison was also made in order to assess what has been called "practice effects" which includes besides practice such variables as learning, adaptation to the laboratory situation and relaxation. On both Day 1 and Day 3, a narrow window condition was run with quantitative feedback and on Day 2, the no incentive condition approximated the surprisal/task relevance contingencies of the narrow window conditions. Thus a two-way repeated measures ANOVA with repeated measures on the three conditions and three types of feedback was calculated.

As a means of investigating the amount of variance in a particular component of the evoked potential that was explained by the variables surprisal, average uncertainty reduction and amount of task relevant information in each stimulus, correlational comparisons were made. Prior to the commencement of each condition subjects were informed of the stringency of the task, i.e., of the likelihood of being correct. In actuality, however, some variation was seen from these objective probabilities. For example, error was not always equally distributed between under and overestimation. Some individuals tended to err more in one direction than the other. Three methods were thus used for calculating the correlations. The first method based the computation of the number of bits of surprisal, task relevant information and so forth on the actual outcome probabilities of occurrence of each stimulus for each subject over the three days of testing. These figures were then correlated with the individual components of the evoked response for each stimulus. A second method took into account individual differences in evoked response amplitude. An attempt was made to "normalize" the comparisons by dividing the amplitude of a particular component evoked by any one stimulus for each subject by the grand mean of that component over the three days for the same subject. The "normalized" individual scores were then correlated with individual response patterns. A final method took into consideration the fact that subjects had a prior expectation of the probability of occurrence of each type of feedback. Variation from this prior expectancy was realized at a time when testing in a particular condition was quite advanced. The "objective" informational score was therefore correlated with the <u>mean</u> amplitude of the evoked potential for each stimulus in a particular condition, again over the three days. In addition to the correlations obtained over the three days, further computations were made on separate days, the exception being Day 2, when a marked restriction of range was encountered.

All statistical analyses were run using the data gathered from the Cz electrode site. When a particular analysis showed consistent significant effects, it was repeated at the Fz and Pz locations. Previous study has indicated that the various components of the evoked potential are often dependent on scalp topography (Courchesne et al., 1975; Donchin et al., 1975; Hillyard et al., 1975; Simson et al., 1976; Squires, N. et al., 1975) The parietal/frontal ratio difference was therefore calculated (Pz - Fz)/ Pz for the three positive components, P2, P3, and P4, for the three types of feedback on two conditions, the middle window of Day 1 and the no incentive condition of Day 2. These ANOVAs, with repeated measures on the feedback and component conditions provided an index of the frontal or reciprocally the parietal dominance of a respective component. As well it permitted a comparison of the influence of scalp location on the amplitude of the positive components of the evoked potential in association with the feedback stimuli. For example, there is reason to propose that disconfirming feedback evoke greater frontal activity than confirming (Luria, 1966a). To investigate the role of scalp topography on the P3 component in particular, the data from the narrow, middle, and wide conditions of Day 1, the four incentive conditions of Day 2, and the quantitative feedback condition of Day 3, were combined. Control and qualitative feedback conditions were not examined. It was assumed that practice effects were equivalent at both frontal and parietal locations. When the Pz-Fz proportional *difference* was calculated, the constant practice effect was subtracted out. Thus, the eight conditions across the three days and the three feedback signals provided data for an 8 x 3 factor repeated measures ANOVA.

In all analyses of variance, where significant main effects were indicated, the *post-hoc* procedure selected was Tukey's honestly significant test -- where significant interaction was found, simple main effects were tested using standard procedures. Careful attention has, however, recently been devoted to the repeated measures error term. A pooled mean square error term for each level was calculated following the Satterthwaite (1946) method. To assess the significance of the *F* ratio for each level of the interaction, an approximation was made by utilizing the appropriate degrees of freedom taken from the standard ANOVA table. The actual differences between simple effects was based on more rigorous and precise methods derived from the critical *t* statistic (Cochran and Cox, 1957, p.299; reported by Winer, 1971, pp.544-545). The actual significance of the *F* ratios was therefore determined by the presence or absence of a critical *t* in follow-up analyses.

All correlational and analyses of variance calculations were run on an IBM 360/120 computer, using the SOUPAC statistical package (Dickman, 1972). Statistical programs, written locally by the present author, were used for testing main and simple main effects.

Special consideration must be paid to the adoption of a univariate technique for the analysis of 10-17 dependent variables, in five experiments, and the possibility of three scalp topographies. The combination results in the possibility of almost 300 separate ANOVAs, markedly increasing the possibility of Type I error (Greenwald, 1976). In view of the exploratory nature of the evoked potential domain, the level of significance was accordingly set at 0.01 for each main and interaction effect of the ANOVA table. Post-hoc follow-up based on the Tukey procedure is quite conservative and contains the necessary compensation for the total number of comparisons to be made. The level of significance was thus set at 0.05 in order to capitalize on differences that might otherwise be overlooked (Type II error).

A number of assumptions must be met with any univariate ANOVA. With the addition of repeated measures, not only must the assumption of homogenity of variance be met, but also an assumption of symmetry of equality of the variance-covariance matrix is also established. Population covariance between pairs of treatment levels must be constant (Kirk, 1968, p. 139).

Computerized statistical techniques are not as yet available to handle the complex procedure, called Box's "M", and even if they were developed the cost of computer core usage would be high indeed. To calculate such a statistic by hand for the large number of experiments and conditions would be an enormous, time-consuming task, the payoff, considering the already accepted wide inter-subject evoked potential variability (Davis, et al., 1966), hardly justifying the effort. Moreover, Geisser and Greenhouse (1958) have developed a conservative _F_ test which provides correct significance levels even in the presence of the most extreme heterogenity of measurements. It is an extremely conservative test and has only been rarely employed in evoked potential research, Knott and Peters (1974) being the exception to the rule. Its computation moreover is fairly basic. The degrees of freedom for _F_ are multiplied by 1/(T-1), where T is the number of levels of a factor. In the case of interaction, this test is especially conservative, sharply decreasing the number of statistically significant rejections of the null hypothesis. If the conservative _F_ is significant, there can be no doubt of the significance of the conventional _F_ ratio, no matter how badly the assumptions of the analysis of variance were violated.

To compensate for the extreme conservatism of the conservative _F_ test, its level of significance was set at 0.10 rather than 0.01. _F_ ratios were considered significant if both the conventional test level of significance exceeded 0.01 and the conservative _F_ exceeded the 0.10 level.

Hypotheses to be Tested

Based on the review of the literature a number of questions may be raised. In Experiment 1-1, are the effects of disconfirming feedback greater than those of confirming feedback regardless of the degree of task relevant information contained in each? Does the stringency of the (defined as the average task relevancy) condition or window size effect either behavioural performance or the components of the evoked potential? Stated in terms of the major null hypotheses these questions are:

1. There is no significant difference between the effects of the stringency of the task brought about by the narrow, middle and wide windows as well as the control condition on behavioural time estimation error or on measures of latency or amplitude of a number of components of the evoked potential.

2. There is no significant difference between the effects of types of feedback stimuli on the latency and amplitude of the components of the evoked potential.

3. There is no significant interaction effect between window size and feedback stimuli on the various physiological measures.

If the treatment condition main effect is significant, the _post-hoc_ comparison between the middle window and control conditions will determine the influence of task relevant information versus surprisal _per se_.

On Day 2, besides a repetition of the consideration of the various types of feedback, incentive and value were the independent variables under scrutiny. The questions of concern then were: What were the effects of negative, positive incentive, or a combination of both on both behavioural and physiological measures. Were these effects different from when no incentive was provided? How did the effect of increasing or decreasing the monetary value attached to a particular stimulus effect the dependent variables? The additional null hypotheses for Experiment 2-1 were thus:

1. There is no significant difference between the effects of negative, positive, negative and positive or no incentive on the behavioural and physiological measures.

2. There is no significant interaction effect between the incentive conditions and types of feedback on the physiological measures.

For Experiment 2-2, which manipulated stimulus value, the null hypothesis was:

1. There is no significant difference between the effects of stimuli varying in value on the behavioural or physiological measures.

In Experiment 3-1, the main conditional effects looked at the differences between average uncertainty reduction (based on probability *per se*) and average task relevancy. Thus the quantitative, qualitative, and control conditions provided the same degree of uncertainty reduction but varied in degree of average task relevancy. With the control placed on average uncertainty reduction, does the degree of average task relevancy effect either behavioural or physiological measures? At the level of individual stimuli, both confirming and disconfirming feedback always contained the same degree of surprisal while confirming signals in the qualitative and quantitative situations equally provided the subject with the same amount of task relevant information. Disconfirming signals in these two conditions however varied in the degree to which they provided subjects with task relevant information. Stated in this manner the question becomes one of interaction: Are the effects of disconfirming feedback independent of their degree of task relevant information? The hypotheses thus for Experiment 3-1 are:

1. There is no significant effect of quantitative, qualitative or random (control) feedback on behavioural or physiological measures.

2. There is no significant interaction effect between quantitative, qualitative, and control conditions and confirming and disconfirming feedback on the physiological measures.

Experiment 3-2 was quite similar to Experiment 3-1, except that in addition it compared two conditions in which the amount of task relevant information contained in disconfirming feedback was equivalent but their amount of surprisal varied. Hence when stimuli contain equal amounts of task relevant information but differ in surprisal what is the effect on the dependent measures? The null hypotheses are the same as in Experiment 3-1.

The dependent measures in these five experiments were a behavioural measure of time estimation: the mean absolute time deviation from the one second standard for each subject, and a number of physiological measures: the latency of N1, P2, N2, P3, N3, and P4 and post-feedback resolution, as well as the base-peak amplitude measures for these components and the pre-feedback CNV. In some instances, peak-to-peak amplitude measures were employed, N1-P2, N1-P3, and N1-P4. In addition to these analyses two other runs were made to assess day-to-day changes in the evoked potential and across scalp differences. Over the three days were changes evident in any of the components of the evoked potential? Did the effects of confirming and disconfirming feedback vary? The major hypothesis stated in the null form was:

1. There is no significant daily effect on the various components of the evoked potential.

Across scalp comparisons, in the form of the Pz/Fz proportional difference, were made in response to the question, do the various components of the evoked potential show different frontal to parietal influences? Are the effects of confirmation and disconfirmation compariable at the two sites? The null hypotheses were thus:

1. There is no significant difference in the Pz/Fz ratio difference between the various components of the evoked potential.

2. There is no significant effect of type of feedback on the Pz/Fz ratio for the various components of the evoked potential.

As well as these primary hypotheses, several other minor ones were tested. The results of the analyses will be presented in the next chapter.

CHAPTER III

Results and Interpretation

Means and standard deviations for all raw scores for the various experiments are presented in Appendices A to E. Data considered to be particularly relevant to the issue at hand are presented in tabular or graphic form in this chapter. Although statistical analyses were conducted on all data reported in the Appendices, space did not permit total incorporation in the body of the thesis. Instead only those of paramount importance were selected for presentation.

The results of Experiment 1-1 will be discussed first. Then the inquiry will jump to Experiments 3-1 and 3-2 due to their integral relationship to 1-1. The analyses of Experiments 2-1 and 2-2 will then be presented concluding with day-to-day comparisons and across scalp analyses.

Experiment 1-1

Three treatment conditions were employed as a means of manipulating the ratio of occurrence of confirming and disconfirming feedback. In a fourth, control condition, feedback was irrelevant, i.e., not contingent on the subject's performance.

In order to achieve these various levels of probability and hence manipulate degree of surprisal and task relevant information, window sizes were either opened or closed according to individual baseline performance (Table 5). The narrow window (mean width = 140 ms) generated 76% error (37% underestimation, 39% overestimation). Conversely the subjects' time estimations fell within the window on only 24% of the trials. When the window was opened by approximately 150 ms (mean for middle window = 285 ms), correct estimations rose to 47%, underestimations dropping to 25% and overestimations to 28%. The correct-incorrect ratio afforded by the middle window was thus in close agreement to the desired 50:50 ratio. Even though the window was opened by another 150 ms (mean = 430 ms) in an attempt to ease the stringency of the task, the actual number of correct estimations fell slightly below the 75% mark. On 69% of the trials a correct estimation was made, while on 31%, errors were made (14% underestimation, 17% overestimation).

When onset of the respective diode was contingent on a randomized computer generated probability schedule and not on performance, it was found that the LED occupying the correct estimation position was flashed on 48% of the trials, while the ones in the incorrect-under and incorrect-over positions were each flashed 26% of the times. These proportions were thus quite similar to the programmed 50:25:25 format.

The mean absolute error from the 1000 ms target was calculated for each of the eight subjects for each of the four treatment conditions. Figure 5 displays a plot of these deviations. The analysis of variance proved to be significant, $\underline{F}$ (3,21) = 4.99, conventional $\underline{p}$ <.01, conservative $\underline{p}$ <.10 (Table 6). The error found in the time estimations carried out in the control were significantly greater than in the three

Figure 5. Mean absolute time estimation error as a function of window size and relevancy of feedback (Experiment 1-1).

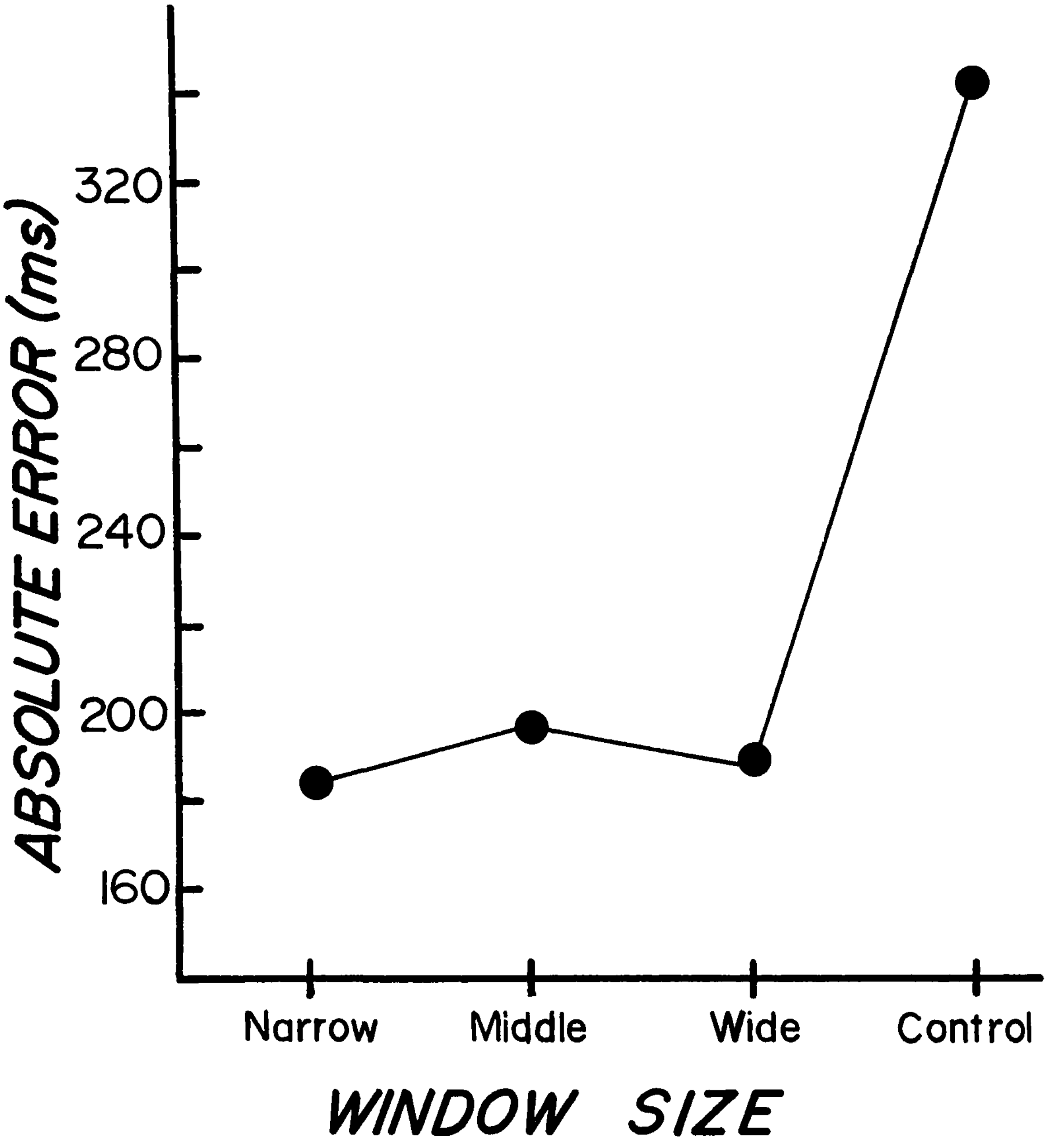

ABSOLUTE ERROR (ms)
320
280
240
200
160
Narrow
Middle
Wide
Control
WINDOW SIZE

Table 6

Analysis of Variance of Behavioural Data of Experiment 1-1 for Narrow, Middle, Wide Windows, and Control

Source of Variation	SS	df	MS	F
Between Subjects				
R	102030	7	14575	
Within Subjects				
A (Treatment)	118262	3	39420	4.99*@
A x R	1165796	21	7895	

Conventional $\underline{F}_{.99}$ (2,31) = 4.87 *Conventional $\underline{p}$ <.01

Conservative $\underline{F}_{.90}$ (1,7) = 3.59 @ Conservative $\underline{p}$ <.10

task relevant feedback conditions. The time estimations incurred between the three conditions when feedback was relevant did not however significantly vary. It appears evident then that on the first day of experimentation, feedback aids in the improvement of performance supporting Adams (1968) proposal.

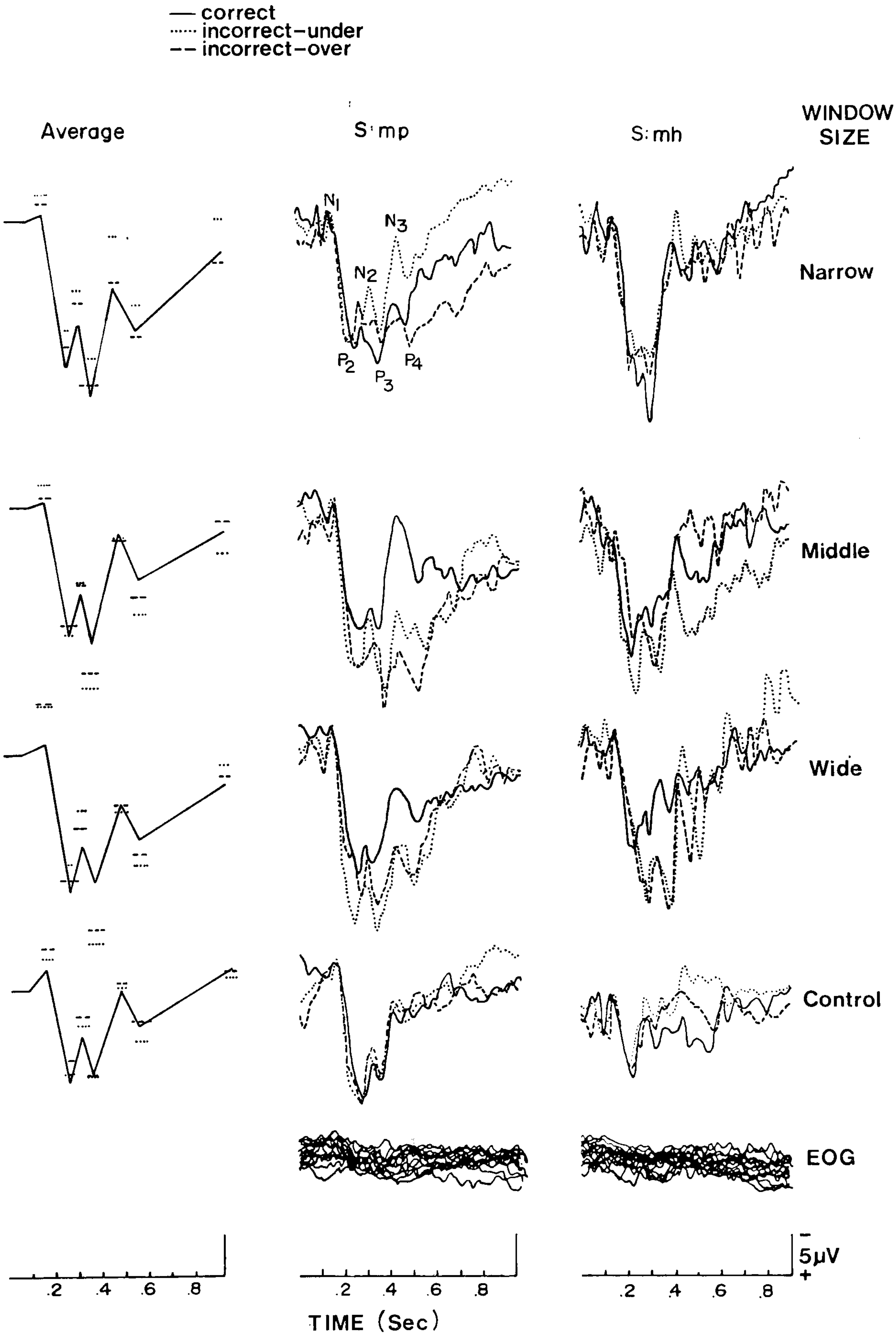
The physiologic data were recorded from three electrode sites, frontal, vertex, and parietal leads, under four treatment conditions in response to three types of feedback signals. A schematic representation of the means for each treatment evoked by the different stimuli is illustrated in Figure 6. Also included are examples of evoked potential records from two subjects. The waveform for the individual subjects represents an average of the replications. Discussion of the evoked potential data will initially concern only the vertex location since it reflects, to some extent at least, the activities of both frontal and parietal cortices.

Between the period of the subject's response and the onset of the feedback stimulus, a very small amplitude CNV developed. Neither treatment nor type of feedback stimulus had any significant effect on the CNV. The amplitude range is small but nevertheless consistent with a recent learning and tone discrimination study (Poon et al., 1974). The small amplitudes are not likely due to the absence of a motor response following the feedback stimulus since it has been demonstrated that slow negative shifts do occur with or without a motor response (Delse et al., 1972; Donchin et al., 1972). It is quite possible, however, that the motor response at the time of the estimation caused positive baseline shift prior to the onset of the feedback stimulus. Moreover, due to the novelty of the task and the laboratory situation, subjects were likely under high levels of anxiety that either via a "ceiling effect" (Knott and Peters, 1974) or internal distraction (Tecce, 1972) have been shown to reduce CNV amplitude. Anxiety and stress appear to be particularly prominent in reducing CNV amplitude when females serve as subjects (Knott and Peters, 1974) as in the present study. The failure to find significantly smaller CNVs with the more stringent conditions fails to support Delse et al's. (1972) and Poon et al's. (1976) findings.

Turning to the post-stimulus events neither task stringency, relevancy, nor type of feedback were significantly differentiated by the latency of onset of the first negative peak, N1. The overall mean latency of 157 ms is in close agreement with the literature considering the low intensity of the LEDs (Courchesne et al., 1975; Simson et al., 1976). Vaughan (1966) for example has shown an indirect relationship between intensity of the stimulus and subsequent latency of the N1 component of the evoked potential.

The amplitude of N1 did however show some interesting trends, albeit,nonsignificant. Both the control and "wide window" conditions evoked N1 components about -2μV larger than either the "narrow" or "middle window" conditions. Attention has been demonstrated to have a significant effect on this component (Hillyard et al., 1973; Picton and Hillyard, 1974). In this experiment it seems unlikely that subjects

Figure 6. Schematic representation of the Cz evoked potential waveform as a function of the independent variables of Experiment 1-1. Also included are sample records from two subjects (MP and MH).


— correct
······ incorrect–under
– – incorrect–over
Average
S:mp
S:mh
WINDOW SIZE
N1
N2
N3
P2
P3
P4
Narrow
Middle
Wide
Control
EOG
−
5μV
+
.2
.4
.6
.8
TIME (Sec)

would be most attentive when feedback was not task relevant or when the task was rather straight-forward. If anything, the opposite would be predicted. The possibility must therefore be raised that the effect was due to a difficulty in defining a precise baseline. Disconfirming signals tended to evoke N1 peaks also about -2μV larger than confirming, this difference just failing to reach significance, $\underline{F}$ (2,14) = 5.36, conventional $\underline{p} < .05$, conservative $\underline{p} < .10$ (Table 7). Attention being a type of pre-stimulus priming cannot account for this post-stimulus sequel since subjects had no a priori means of predicting the outcome of their performance.

The likelihood of a baseline bias for disconfirmation is further substantiated by the results of the P2 and the combined N1-P2 components. Disconfirming feedback were associated with an approximately 2μV decrease in P2 when compared to confirming feedback. Thus for the N1-P2 "vertex" potential both confirming and disconfirming feedback evoked almost exactly the same degree of response, in agreement with a number of previous feedback studies.

Significant P2 differences were however revealed within the four treatment conditions, $\underline{F}$ (3,21) = 4.61, conventional $\underline{p} < .01$, conservative $\underline{p} < .10$. Post-hoc procedures indicated that irrelevant, control stimuli significantly attenuated P2 amplitude, while no differences were noted among the three conditions employing task relevant feedback. The consequences of the relevancy of the stimulus for the subject are therefore unveiled as early as P2 (mean latency = 241 ms). Recently Naatanen

Table 7

Analysis of Variance of N1 Amplitude
(Cz Location) under Narrow, Middle,
Wide Window and Control Conditions
for Confirming, Disconfirming --
Under, and Over Feedback

Source of Variation	SS	df	MS	F
A (Condition)	125.74	3	41.91	3.32
A x R (Replication)	265.19	21	12.62	
B (Feedback)	109.93	2	54.97	5.36*@
B x R	143.53	14	10.25	
A x B	49.28	6	8.21	.94
A x B x R	366.68	42	8.73	
R	405.17	7	57.88	

Conventional $\underline{F}_{.95}$ (2,14) = 3.74 * Conventional $\underline{p}$ <.05

Conservative $\underline{F}_{.90}$ (1,7) = 3.59 @ Conservative $\underline{p}$ <.10

(1975) and Wilkinson and Ashby (1974) have suggested that P2 may simply be a reflection of the prolongation of the later positive component, P3, a suggestion also made by Picton and Hillyard (1974). The attenuation of negative components (CNV and N1) in this study and the rather large amplitude P2 component (mean = 15.21μV) considering the low intensity of the stimuli provide partial evidence for this point of view. Moreover P2 is smallest when P3 is smallest -- when stimuli are irrelevant.

The overall N1-P2 component revealed the same influence of relevancy, $\underline{F}$ (3,21) = 5.64, conventional $\underline{p} < .01$, conservative $\underline{p} < .05$. Jenness (1972a, 1972b) and Sutton et al. (1965) have also reported parallel effects for what they termed "salience" of the stimulus. The degree of task relevant information contained in the feedback in the other conditions played little role at this stage of the analysis as evidenced by the very similar N1-P2 amplitudes (Figure 7). Table 8 presents the summary of the analysis of variance.

No significant latency changes were manifested by P2 or the next negative peak, N2. The amplitude of N2 approached significance both for treatment, $\underline{F}$ (3,21) = 4.10, conventional $\underline{p} < .05$, conservative $\underline{p} < .10$ and feedback main effects, $\underline{F}$ (2,14) = 4.95, conventional $\underline{p} < .05$, conservative $\underline{p} < .10$. The N2 changes parallel those for P2, the irrelevant, control condition being associated with more negative N2 components. If N2 is looked upon as representing an index of rebound from P2 or of positive "pull" from P3, then P2-N2 peak-to-peak differences might be a more appropriate measure. It did not show any significant

Figure 7. N1-P2 mean amplitude (Cz location) plotted as a function of the independent variables of Experiment 1-1.

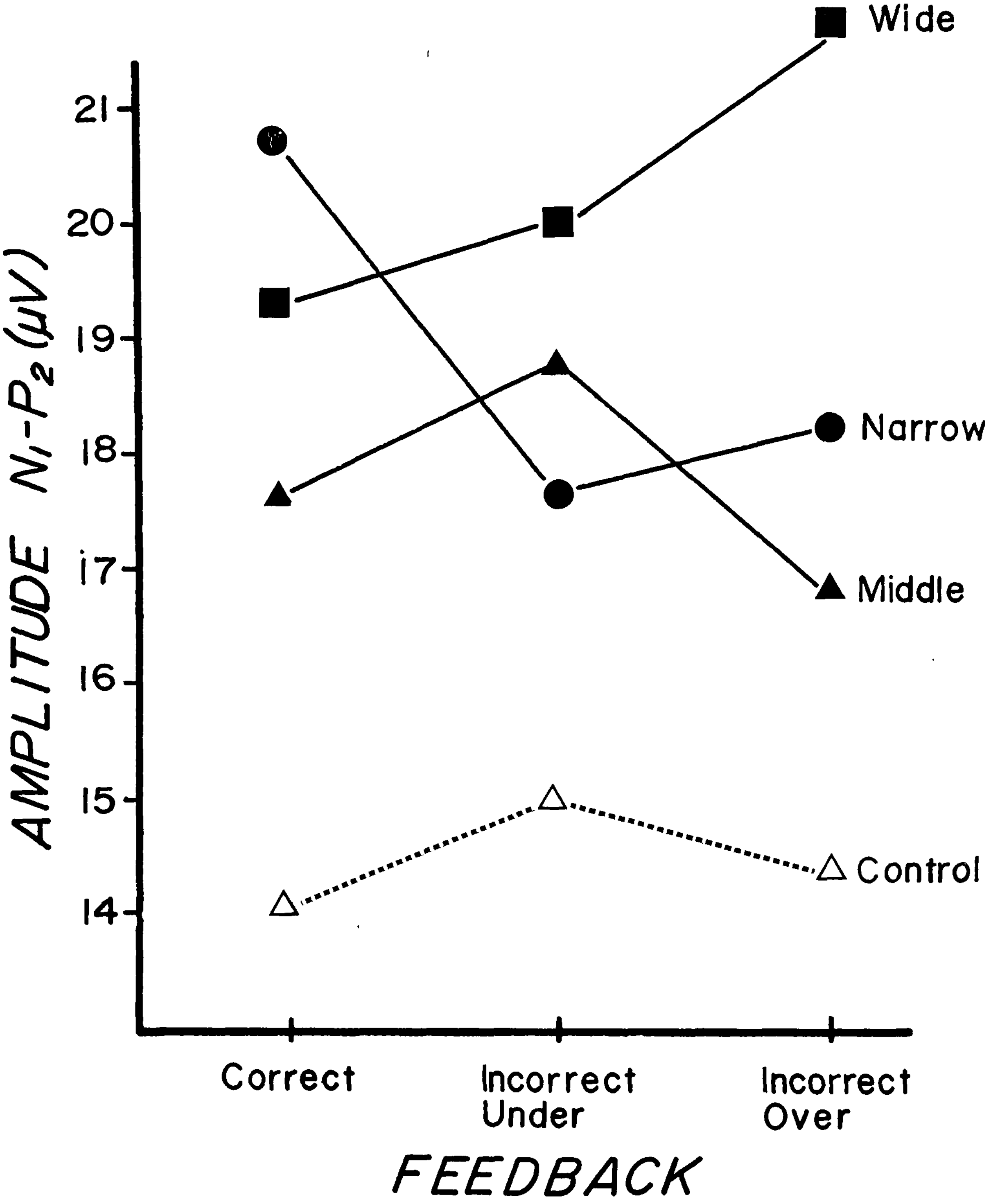

Wide
Narrow
Middle
Control
AMPLITUDE N_1-P_2 (µV)
21
20
19
18
17
16
15
14
Correct
Incorrect Under
Incorrect Over
FEEDBACK

Table 8

Analysis of Variance of N1-P2 Amplitude (Cz Location) under Narrow, Middle, Wide Window and Control Conditions for Confirming Disconfirmating - Under, and Over Feedback

Source of Variation	SS	df	MS	F
A (Condition)	448.88	3	149.62	5.64*@
A x R (Replication)	556.87	21	26.52	
B (Feedback)	.01	2	.01	.00
B x R	432.61	14	30.90	
A x B	95.42	6	15.90	.89
A x B x R	747.48	42	17.80	
R	1442.68	7	206.10	

Conventional $\underline{F}_{.99}$ (3,21) = 4.87 * Conventional $\underline{p}$ <.01

Conservative $\underline{F}_{.90}$ (1,7) = 3.59 @ Conservative $\underline{p}$ <.10

differences between treatment conditions, F< 1.0. An analagous explanation may account for the N2 discrepancy between confirming and disconfirming feedback. P2 was of lower amplitude for the latter while N2 was more negative. P2-N2 differences were however nonsignificant, F< 1.0, once again suggesting that whatever baseline N2 differences were found were due largely to P2 effects.

Because the degree of task relevant information contained in the stimulus (probability of occurrence of a specific stimulus) had no influence on N2 amplitude determination, the "orienting" type N2 response reported by Ford et al. (1976) and Haider et al. (1968) was not in evidence in this experiment. Relatively rare, unpredictable events such as disconfirmation within the wide window condition or confirmation within the narrow window did not evoke larger N2 peaks than the more common, predictable events. It might well be that N2 is an index of the orienting response only when the subject is passive or when the level of arousal is low, neither of which were true in the present case as evidenced both by the physiologic and behavioural data. An interesting consideration is the rather compelling failure of N2 to reach baseline. Indeed with relevant feedback N2 remained approximately 10μV below base, pointing to a continued suppression of negative-going elements (CNV, N1, N2) in favour of what Wilkinson and Ashby refer to as a "wave of positivity."

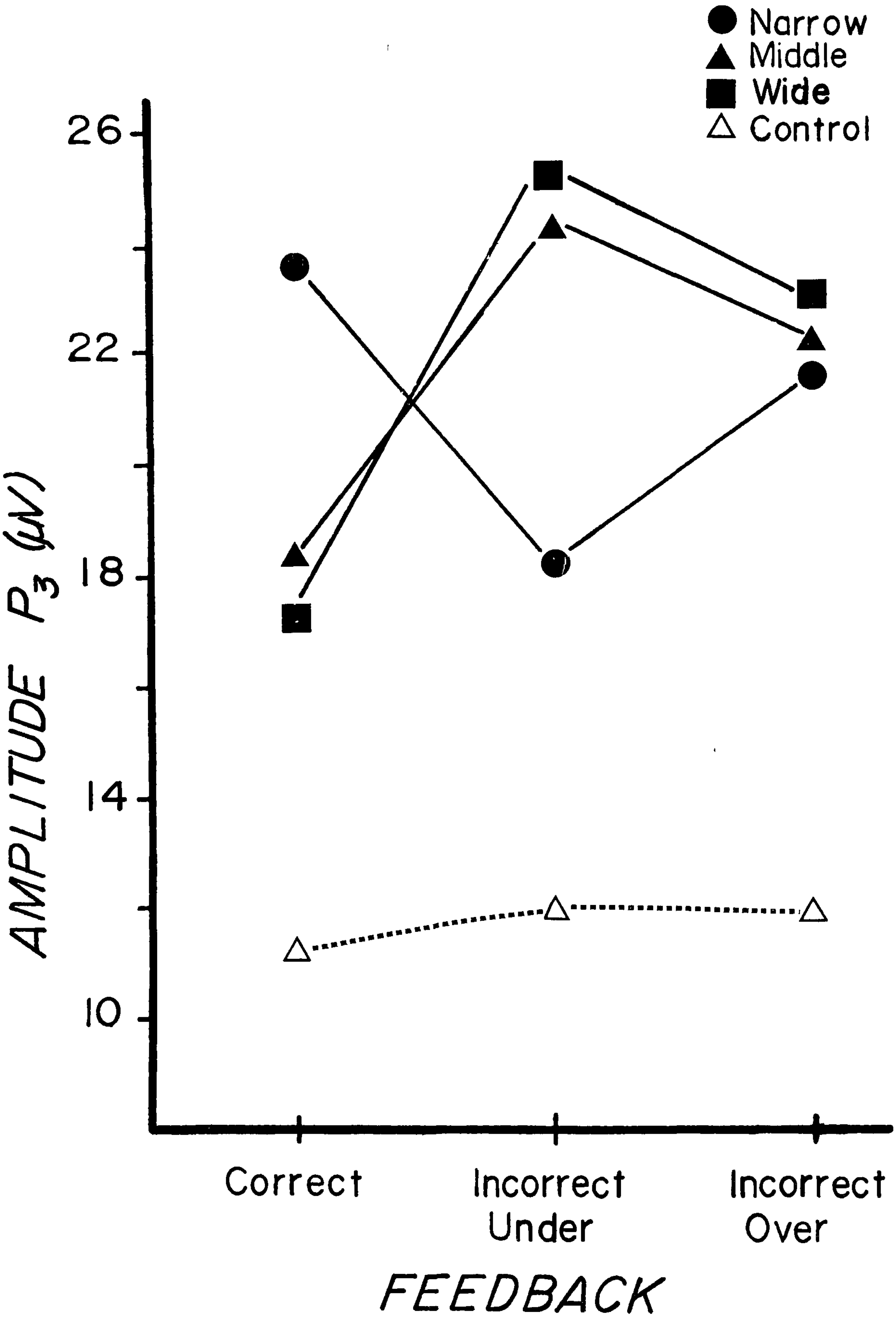
The late positive component or P3 was the peak of primary attention in the study. Statistical analyses of P3 amplitude revealed a significant treatment x feedback interaction, F (6,42) = 3.68, conventional

$\underline{p} < .01$, conservative $\underline{p} < .10$. Testing of simple main effects showed that firstly, task relevant feedback whether they be confirming or disconfirming and regardless of their probability of occurrence evoked significantly larger P3s than the control, irrelevant stimuli. Because the stimuli in both the control and middle window conditions were equally surprising but varied in amount of task relevant information, surprisal per se would not appear to be a major correlate of P3.

The amplitude of P3 evoked by confirming feedback was significantly larger when the window was at its narrowest (probability of confirmation was small) than when it was at its maximum width (probability of confirmation was high). The drop in amplitude associated with confirmation from the narrow to middle window conditions was not significant nor was the difference between middle and wide windows significant.

When feedback informed the subject of an underestimation, P3 was significantly reduced with the narrow window (probability of occurrence was high) than with either the middle or wide windows (medium and low probabilities of occurrence respectively). No differences were apparent between the middle and wide windows. In the case of overestimation, P3 amplitude remained quite high regardless of the width of the window. Probability or, more specifically, amount of task relevant feedback had only a minor role to play in the determination of the overestimation P3. The mean P3 amplitude for the various conditions are plotted in Figure 8. The analysis of variance data is summarized in Table 9 and the simple main effects analysis in Table 9a.

Figure 8. Base - P3 mean amplitude (Cz location) plotted as a function of decision outcome and window size, Experiment 1-1.



● Narrow
▲ Middle
■ Wide
△ Control
26
22
18
14
10
AMPLITUDE P_3 (µV)
Correct
Incorrect Under
Incorrect Over
FEEDBACK

Table 9

Analysis of Variance of P3 Amplitude (Cz Location) under Narrow, Middle, Wide Window and Control Conditions for Confirming, Disconfirming -- Under, and Over Feedback

Source of Variation	SS	df	MS	F
A (Condition)	1706.53	3	568.85	9.56
A x R (Replication)	1250.11	21	59.53	
B (Feedback)	89.58	2	44.79	1.85
B x R	339.66	14	24.26	
A x B[a]	454.33	6	75.72	3.68*@
A x B x R	863.77	42	20.57	
R	3276.90	7	468.13	

[a] Analysis of variance results for simple main effects are presented in Table 9a

Conventional $\underline{F}_{.99}$ (6,42) = 3.26 * Conventional $\underline{p} < .01$

Conservative $\underline{F}_{.90}$ (1,7) = 3.59 @ Conservative $\underline{p} < .10$

Table 9a

Analysis of Variance of Simple Main Effects for A x B Interaction in Table 9

Source of Variation	ss	df	MS	F
A at B				
A at b1 (Correct)	618.51	3	206.17	10.02*
A at b2 (Under)	896.63	3	298.88	14.53*
A at b3 (Over)	646.77	3	215.59	10.48*
B at A				
B at a1 (Narrow)	136.71	2	68.36	3.32*
B at a2 (Middle)	149.36	2	74.68	3.63*
B at a3 (Wide)	256.45	2	128.23	6.23*
B at a4 (Control)	1.45	2	.72	.03*

See page 93 of text for explanation of derivation of error term and _F_ significance

* $p<.05$

Why underestimation would exhibit probability influences and not overestimation is not easily explained. The baseline bias that was tentatively proposed for the P2 results may also have affected those of P3. Using an N1-P3 peak-to-peak measure, a second significant treatment x feedback interaction was found, $\underline{F}$ (6,42) = 3.95, conventional $\underline{p} < .01$, conservative $\underline{p} < .10$ (Table 10). Simple main effects testing (Table 10a) almost exactly duplicated the earlier P3 analysis, the sole exception being that for underestimation, the difference between the means of the wide and middle window conditions was no longer significant, while the significant narrow-wide window amplitude difference was re-confirmed, it possibly being a chance phenomenon. The mean N1-P3 amplitude for the various conditions is illustrated as Figure 9.

Examining the various types of feedback at each treatment level, it was noted that with the narrow window,confirming stimuli (probability of occurrence was low) evoked larger P3 components than disconfirming-under feedback, this difference however failing to reach significance when the N1-P3 measure was employed. The confirming-disconfirming-over difference was not significant with either the P3 or N1-P3 measures. Tueting et al. (1971) presented clear evidence that unpredictable, rare events evoked larger P3 waves than predictable ones, a finding confirmed by several authors (Donchin et al., 1972; Rohrbaugh et al., 1974; Squires et al., 1973a). In the present experiment, when confirmation was unlikely (when the window was narrow), upon occurrence of correct feedback, P3 was not significantly larger than upon the occurrence of either

Figure 9. N1-P3 mean amplitude (Cz location) plotted as a function of decision outcome and window size, Experiment 1-1.

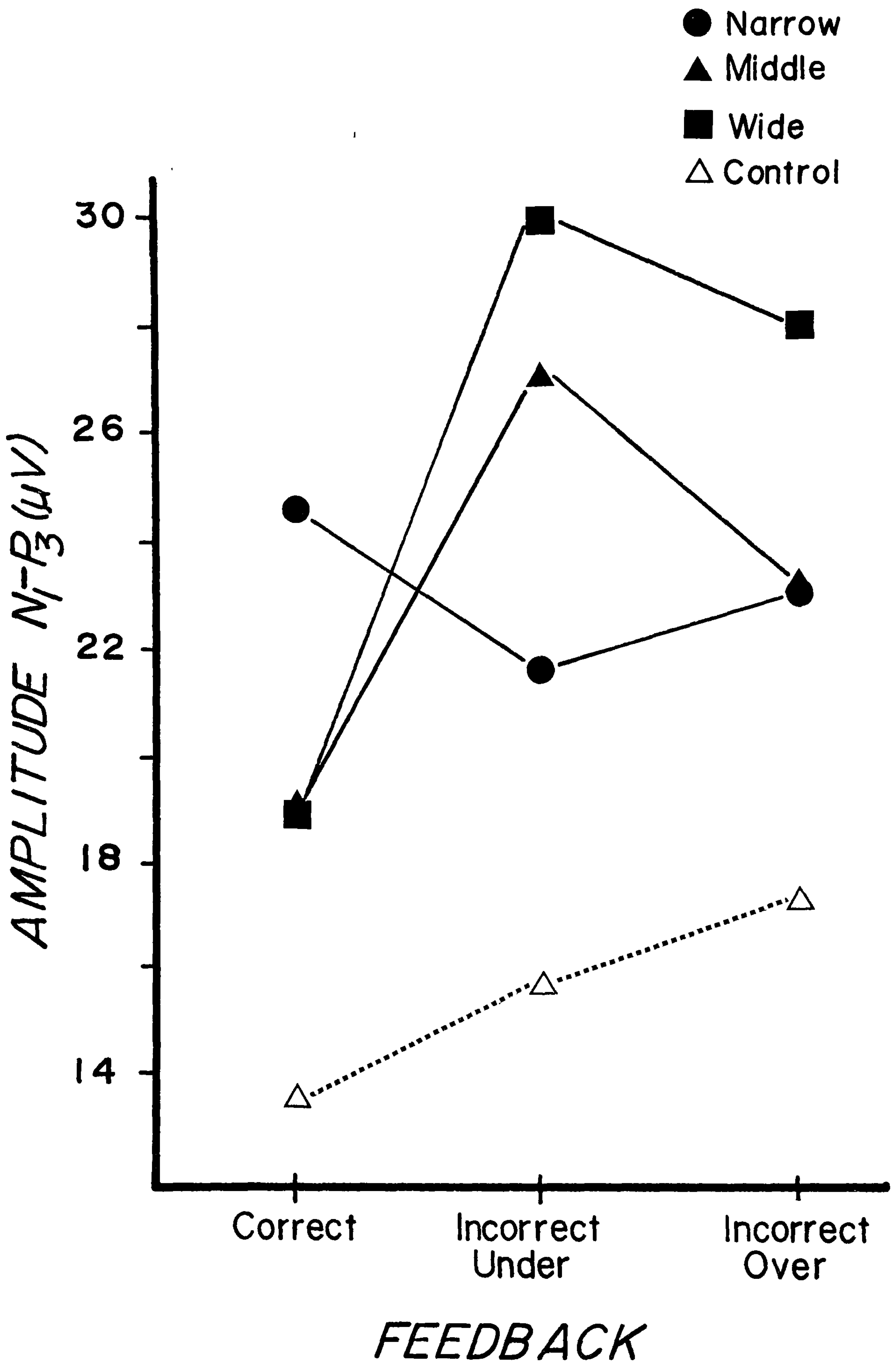

● Narrow
▲ Middle
■ Wide
△ Control
30
26
22
18
14
AMPLITUDE N_1-P_3 (µV)
Correct
Incorrect Under
Incorrect Over
FEEDBACK

Table 10

Analysis of Variance of N1-P3 Amplitude (Cz Location) under Narrow, Middle, Wide Window and Control Conditions for Confirming, Disconfirming -- Under and Over Feedback

Source of Variation	SS	df	MS	F
A (Condition)	1319.98	3	439.66	12.44
A x R (Replication)	741.96	21	35.33	
B (Feedback)	397.51	2	198.76	6.25
B x R	445.11	14	31.79	
A x B[a]	518.58	6	86.43	3.95*@
A x B x R	918.92	42	21.88	
R	3211.88	7	458.83	

[a] Analysis of variance results for simple main effects are presented in Table 10a

Conventional $\underline{F}_{.99}$ (6,42) = 3.26 * Conventional $\underline{p}$ <.01

Conservative $\underline{F}_{.90}$ (1,7) = 3.59 @ Conservative $\underline{p}$ <.10

Table 10a

Analysis of Variance of Simple Main Effects
for A x B Interaction in Table 10

Source of Variation	SS	df	MS	F
A at B				
A at b1 (Correct)	462.78	3	154.26	7.05*
A at b2 (Under)	907.87	3	302.62	13.83*
A at b3 (Over)	466.68	3	155.56	7.11*
B at A				
B at A1 (Narrow)	32.78	2	16.39	.75
B at A2 (Middle)	236.66	2	118.33	5.41*
B at A3 (Wide)	595.33	2	297.67	13.60*
B at A4 (Control)	51.42	2	25.71	1.18*

See page 93 of text for explanation of derivation of error term and _F_ significance

* $p < .05$

incorrect-under or incorrect-over feedback. In actuality, however, the probability of confirmation was not that much less unlikely than for either under or overestimation, the ratio being 25 : 37.5 : 37.5. It might be that the power of the analyses of variance was not strong enough to detect small differences associated with only slight variation in the amount of task relevant information in the stimuli. For this reason a Pearson r correlation was calculated between the objective measure of amount of task relevant information contained in a stimulus and the resultant P3 and N1-P3 mean amplitudes for the eight subjects. The correlations were highly significant reaching .92 for P3 and .97 for N1-P3, indicating that in this experiment at least, the amplitude of the LPC is largely determined by task relevant information values.

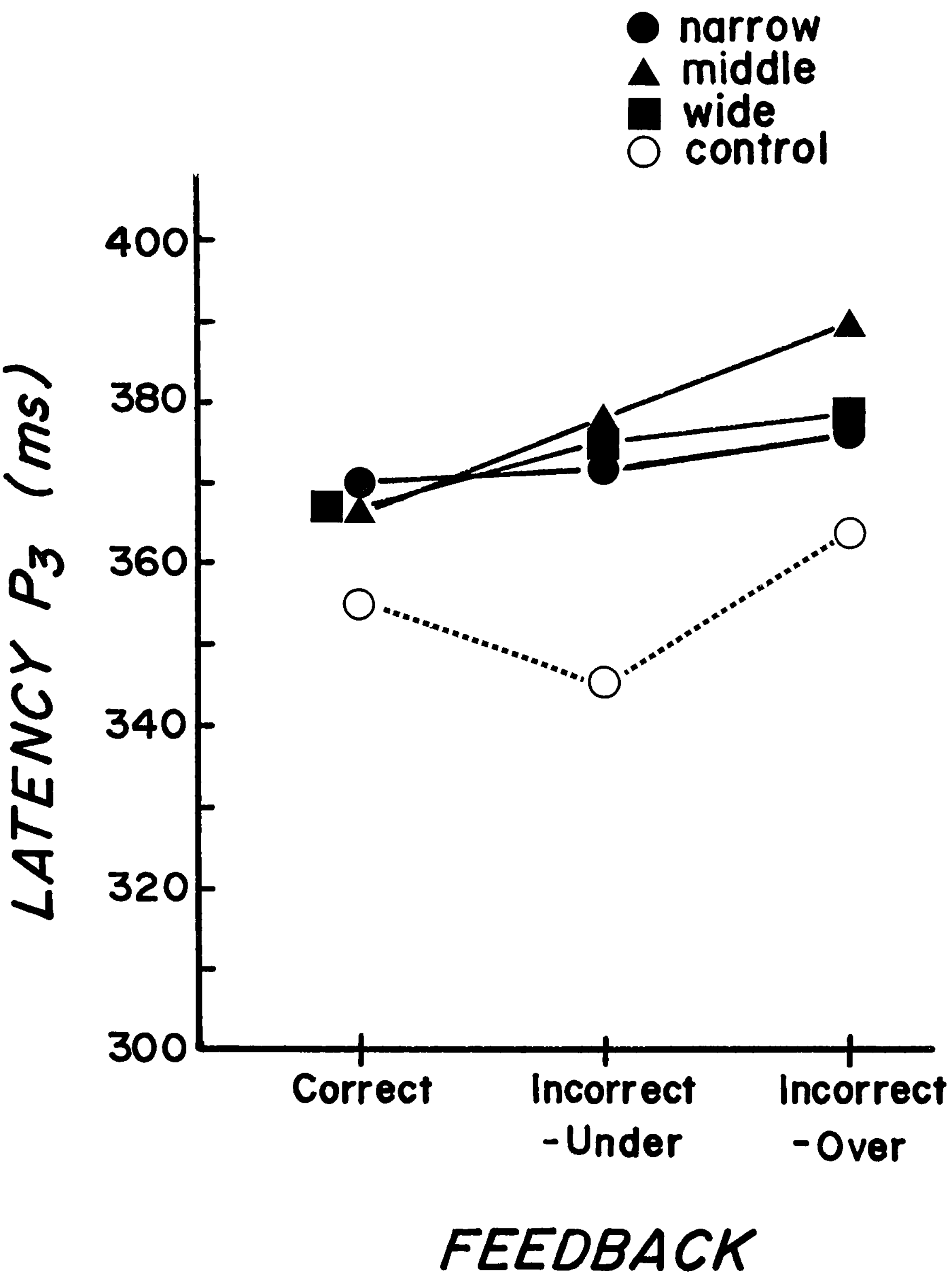
The effects of relevancy of the feedback signal were noted as early as P2, the process of decoding relevant feedback information obviously requiring tremendous neural activity. The moment stimuli take on a relevant feedback role, other factors come into play as reflected in P3. Depending on the amount of information in the stimulus, variable degrees of cortical involvement will be precipitated. It does not necessarily follow that incorrect trials invoke greater informational processing demands than correct ones. Confirmation when it contains greater information than disconfirmation, may perhaps require additional cortical activity. Thus, in order of importance the determinants of the feedback P3 are (1) whether the stimulus is task relevant or not (2) if relevant, the amount of information that the stimulus contains (3) to a limited extent, surprisal. Experiments 3-1 and 3-2 further investigated the degree of task relevancy/surprisal controversy in the case of the narrow window.

P3 latency did not manifest any significant main or interaction effects. Figure 10 shows that the mean latency for task relevant confirming feedback was 368 ms while for disconfirming-under and over feedback it was 375 and 381 ms respectively. Squires et al. (1973a) found shorter latencies with confirming feedback hypothesizing that disconfirmation extended informational processing demands. Such latency differences appear isolated perhaps specific to their particular task. Neither the present nor the majority of other feedback studies have substantiated these findings (Donchin et al., 1973; Poon et al., 1974; Tueting et al., 1971).

Components later than P3 have only recently been studied and then only tersely interpreted. A negative peak immediately after P3, labelled "N3", may imply a recovery or rebound from the earlier decision process. A continuation of the decision process would give rise to a positive "pull" on N3 causing it to fall below baseline.

Latency differences continued to be of little consequence. Neither main nor interaction effects proved to be significant. When N3 amplitude was analyzed, significant treatment differences were found, $\underline{F}$ (3,21) = 6.02, conventional $\underline{p} < .01$, conservative $\underline{p} < .05$, task relevancy again being the major contributor to these differences. Irrelevant stimuli produced significantly more negative N3 components than in relevant feedback when the window size was either narrow or wide. The various types of feedback had no effect on N3 amplitude.

Figure 10. Mean latency of the P3 component (Cz location) plotted as a function of decision outcome and window size.


● narrow
▲ middle
■ wide
○ control
LATENCY P_3 (ms)
400
380
360
340
320
300
Correct
Incorrect -Under
Incorrect -Over
FEEDBACK

A still later component, P4, showed more exaggerated treatment effects, F (3,21) = 8.86, conventional $p < .01$, conservative $p < .05$. Regardless of the window size, task relevant feedback amplified P4 two to three times the size of the irrelevant stimuli P4, the differences between these means being significant. P4 then appears to be a continuation of feedback regulation reflecting as a type of re-programming and re-evaluation of the situation at hand. Unfortunately, very little data is currently available describing the P4 process. The most extensive study to-date (Stuss et al., 1976) noted that P4 was largest when subjects were attempting to find a solution to a complex concept formation task, being primarily related to error. In the present context, no such error – P4 association was found. Disconfirmation did provide for a 13% increase in amplitude, the differences between the types of feedback however not being statistically significant, F (2,14) = 1.83, conventional $p < .01$, conservative $p < .10$. The summary of the analysis of variance of the P4 component appears as Table 11. In the current experiment it is possible that P4 was part of a prolonged P3 process rather than a separate component.

When the N1 bias was taken into account, important alterations ensued. At the same time that the task relevancy effects were enlarged, F (3,21) = 8.90, conventional $p < .01$, conservative $p < .05$, significant N1-P4 feedback differences were now established, F (2,14) = 8.12, conventional $p < .01$, conservative $p < .05$. Following post-hoc procedures it was noted that both types of disconfirmation, under and overestimation

Table 11

Analysis of Variance of P4 Amplitude (Cz Location) under Narrow, Middle, Wide Window and Control Conditions for Confirming, Disconfirming -- Under and Over Feedback

Source of Variation	SS	df	MS	F
A (Condition)	999.61	3	333.20	8.86 * @
A x R (Replication)	789.57	21	37.60	
B (Feedback)	48.14	2	24.07	1.83
B x R	183.72	14	13.12	
A x B	185.97	6	31.00	1.93
A x B x R	673.87	42	16.04	
R	543.54	7		

Conventional $\underline{F}_{.99}$ (3,21) = 4.87 * Conventional $\underline{p} <.01$

Conservative $\underline{F}_{.95}$ (1,7) = 5.59 @ Conservative $\underline{p} < .05$

were related to larger mean scores than confirmation. Differences due to window size did not significantly alter N1-P4 amplitude. Mention is nevertheless made of the fact that confirming feedback evoked P4s equal in amplitude to those evoked by disconfirming feedback when the width of the window was narrow. The dominant role taken by disconfirmation was manifested as the window was opened. Interaction effects were however not significant (Table 12).

N1-P4 seems to represent a more tenable explanation of the findings than P4. It was expected that disconfirming stimuli, which in general, contained higher levels of task relevant information, would be associated with greater cortical activity as reflected in P4 activity than confirming feedback.

The final measure, post-feedback resolution,may be an index of the degree of continuation of informational processing. Significant treatment differences were again found, $\underline{F}$ (3,21) = 6.15, conventional $\underline{p} < .01$, conservative $\underline{p} < .05$, task relevance again being the major influence. Conditions in which feedback was task relevant regardless of window size were seen to be linked with continued positivity -- post-feedback resolution failing to reach baseline. Type of feedback however had no significant effect, $\underline{F} < 1.0$. Although a significant interaction was indicated, $\underline{F}$ (6,42) = 4.67, conventional $\underline{p} < .01$, conservative $p < .05$, an examination of the means and standard deviations of individual conditions suggests a random, chance configuration. There seems to be no reason, for example, to account for the fact that overestimation trials

Table 12

Analysis of Variance for N1-P4 Peak-to-Peak Measure (Cz Location) for Correct, Under, and Overestimation Feedback Signals under Narrow, Middle, Wide, and Control Treatment Conditions

Source of Variation	SS	df	MS	F
A (Treatment)	773.49	3	257.83	8.90 * @
A x R (Replication)	608.15	21	28.96	
B (Feedback)	303.23	2	151.62	8.11 * @
B x R	261.51	14	18.68	
A x B	161.23	6	26.87	1.76
A x B x R	639.83	42	15.23	
R	1207.60	7	172.51	

Conventional $F_{.99}$ (3,21)= 4.87

Conventional $F_{.99}$ (2,14)= 6.51

Conservative $F_{.95}$ (1,7) = 5.59

* conventional p <.01

@ conservative p <.05

remained 5.57 μV below baseline while underestimation trials returned to within .34 μV of the baseline under the narrow window condition. When the middle window was employed, the reverse was true, underestimation trials remaining 6.13 μV below baseline and overestimation trials approaching to within 1.88 μV of it. In addition, wide inter-subject variability makes any specific interaction interpretation of resolution indeed tentative.

Analysis of the various components of the evoked potential was carried out at two additional scalp sites, frontal and parietal locations. The results will be presented succinctly indicating where overall amplitude was greatest and where experimental manipulations were most effective.

N1, although small in amplitude, over the entire scalp region, was largest parietally supporting previous visual evoked potential research (Lehtonen, 1973; Simson et al., 1976). The treatment and stimulus main effects that just failed to reach significance centrally were significant frontally even though the N1 grand mean was small, $\underline{F}$ (3,21) = 5.06, conventional $\underline{p} < .01$, conservative $\underline{p} < .10$, and $\underline{F}$ (2,14) = 7.86, conventional $\underline{p} < .01$, conservative $\underline{p} < .05$. Control stimuli evoked larger N1 amplitudes than relevant feedback signals when the width of the window was either narrow or medium. Disconfirming feedback produced a significant increase of approximately -2 μV in amplitude compared to confirming. The latter finding might be indicative of the beginnings of a frontal decision process related to feedback activity (Luria, 1966a,b; Pribram, 1969). Simson et al. (1976) have shown that the N_x related to the detection of a missing visual stimulus takes on significant frontal qualities.

Considering the P2 component, the significant central decrease in magnitude seen with irrelevant stimuli was replicated both frontally, F (3,21) = 7.03, conventional $p < .01$, conservative $p < .05$ and parietally, F (3,21) = 9.16, conventional $p < .01$, conservative $p < .05$. No feedback differences were found at any location. The analysis of variance for the Fz location appears as Table 13, while that for the Pz electrode appears as Table 14.

The combined N1-P2 component was largest at the parietal site where treatment influences were most marked, F (3,21) = 10.50, conventional $p < .01$, conservative $p < .05$. Frontally, N1 treatment differences went almost opposite those of P2, the frontal N1-P2 peak-to-peak measure therefore failing to find any significant treatment effects, F (3,21) = 3.11, conventional $p < .01$, conservative $p < .10$. That initial encoding and processing of higher order stimuli is maximal in central-parietal regions is consistent with the generally accepted "simultaneous processing" role of this region (Das et al., 1975; Luria, 1966a, 1966b).

The amplitude of P3 was quite large at all three sites, being equal at central and parietal regions but reduced by 20% in the frontal region. These topographical maps appear to be quite similar to the feedback P3 maps of Hillyard et al. (1975) and Poon et al. (1974). Most P3 studies have typically located P3 parietally,the exception being the "orienting response" P3 (Courchesne et al., 1975; Ford et al., 1976; Squires, N. et al., 1975). Feedback activity on the other hand has been deemed a function of the frontal lobes (Anokhin, 1969; Luria, 1966a, b; Pribram,

Table 13

Analysis of Variance for P2 Component (Fz Location) for Correct, Under, and Overestimation Feedback Signals under Narrow, Middle, Wide, and Control Treatment Conditions

Source of Variation	SS	df	MS	F
A (Treatment)	387.66	3	129.22	7.03 *@
A x R (Replication)	385.91	21	18.38	
B (Feedback)	16.41	2	8.20	.55
B x R	209.79	14	14.99	
A x B	47.54	6	7.92	.50
A x B x R	660.75	42	15.73	
R	970.19	7	138.60	

Conventional $F_{.99}$ (3,21) = 4.87

Conservative $F_{.95}$ (1, 7) = 5.59

* conventional $p < .01$

@ conservative $p < .05$

Table 14

Analysis of Variance for P2 Component (Pz Location) for Correct, Under, and Overestimation Feedback Signals under Narrow, Middle, Wide, and Control Treatment Conditions

Source of Variation	SS	df	MS	F
A (Treatment)	579.12	3	193.04	9.16 *@
A x R (Replication)	442.50	21	21.07	
B (Feedback)	1.95	2	.97	.06
B x R	225.13	14	16.08	
A x B	73.81	6	12.30	1.46
A x B x R	352.83	42	8.40	
R	1280.39	7	182.91	

Conventional $F_{.99}$ (3,21) = 4.87

Conservative $F_{.95}$ (1, 7) = 5.59

* conventional $p < .01$

@ Conservative $p < .05$

1969). The influence of both areas therefore might be responsible for the widespread P3 effects in the present experiment.

The feedback P3, which was largest centro-parietally, manifested greatest variation frontally, where the effects of the experimental manipulations were even more striking than were observed at Cz. Significant treatment x stimulus interaction was revealed, F (6,42) = 4.24, conventional $p < .01$, conservative $p < .10$. A greater differentiation between confirming and disconfirming feedback was indicated following the simple main effects testing. Confirming feedback never evoked significantly larger P3s than disconfirming in spite of informational content variation, both under and overestimation being associated with larger P3s than correct estimation when the window size was at mid distance or at its widest. N1-P3 data were essentially similar. The clear effects seen with the different classes of feedback at the frontal site were largely blurred parietally. For example, no P3 differences existed between feedback that indicated correct, under or overestimation under the middle window condition. Tables 15 and 15a presented the analyses of variance of the frontal data and the results of the simple main effects testing while Table 16 presents the analysis of variance for the parietal data. Figure 11 is a plot of the means of the P3 component for the three scalp locations with the middle window condition, while Figure 12 depicts actual records from one subject. The issue of scalp topography will be discussed in greater detail later in this chapter.

Figure 11. Mean Base-P3 amplitude for the middle window condition, Experiment 1-1, plotted as a function of electrode placement and decision outcome.

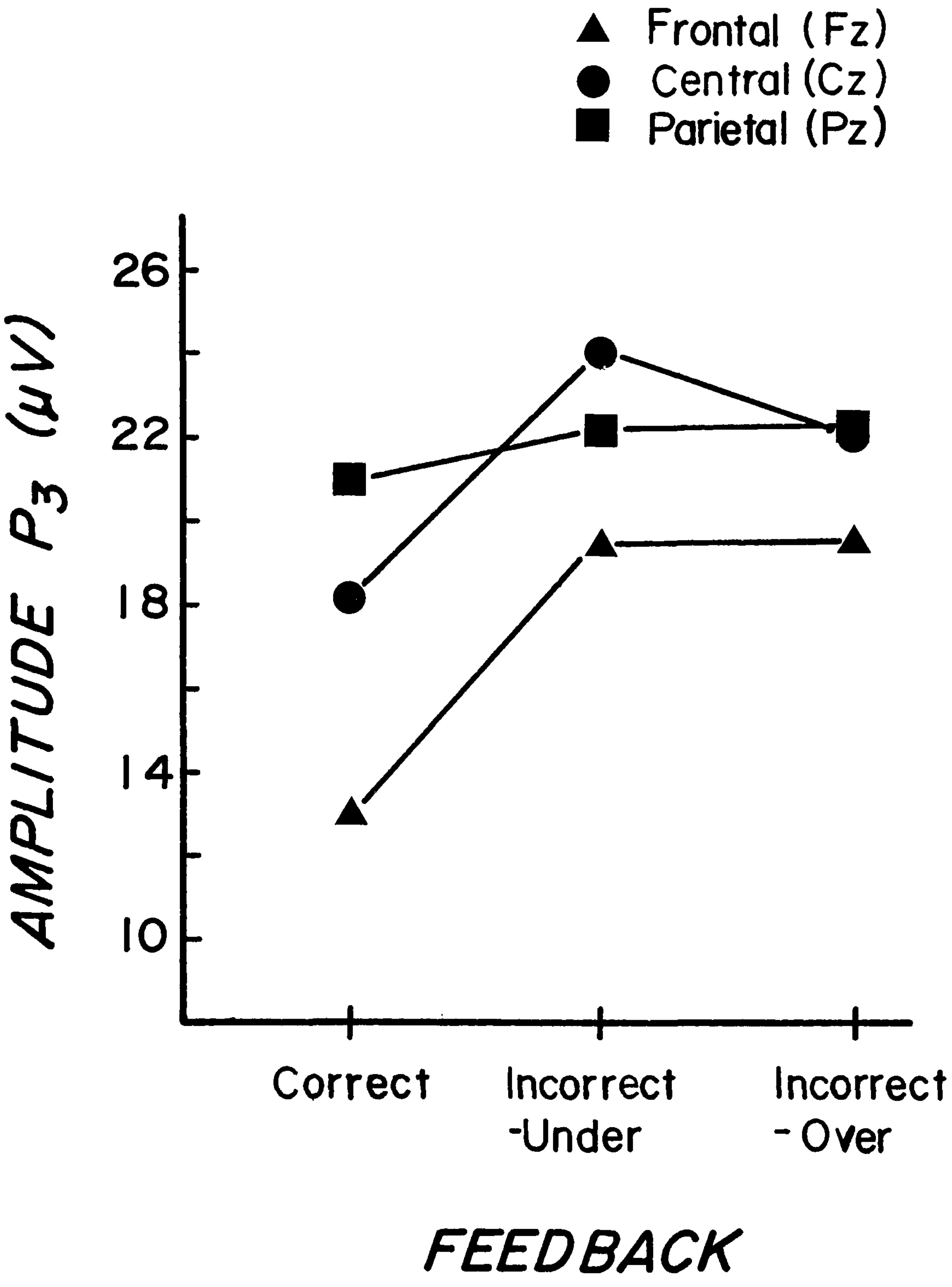
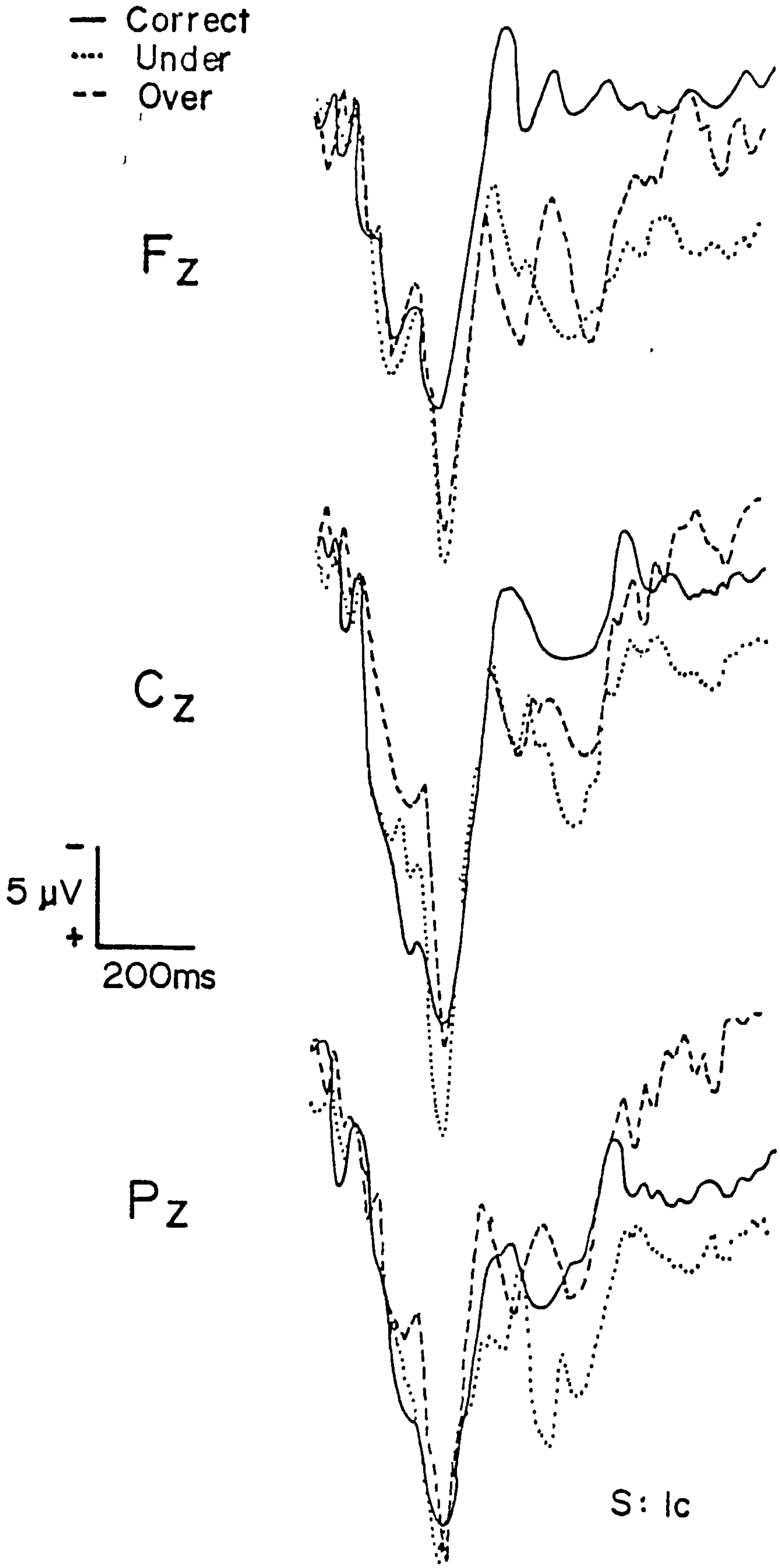

▲ Frontal (Fz)
● Central (Cz)
■ Parietal (Pz)
AMPLITUDE P_3 (μV)
26
22
18
14
10
Correct
Incorrect -Under
Incorrect - Over
FEEDBACK

Figure 12. Evoked potential waveform at frontal, central, and parietal sites for the middle window condition, Experiment 1-1, for one subject, LC.



Correct
Under
Over
Fz
Cz
Pz
-
5 µV
+
200ms
S: lc

Table 15

Analysis of Variance for P3 Component (Fz Location) for Correct, Under, and Overestimation Feedback Signals under Narrow, Middle, Wide, and Control Treatment Conditions

Source of Variation	SS	df	MS	F
A (Treatment)	1378.49	3	459.50	15.19 * @@
A x R (Replication)	635.36	21	30.26	
B (Feedback)	255.77	2	127.88	4.11
B x R	435.96	14	31.14	
A x B[a]	558.43	6	93.07	4.24 * @
A x B x R	921.53	42	21.94	
R	2605.66	7	372.23	

Conventional $F_{.99}$ (3,21) = 4.87

Conventional $F_{.99}$ (6,42) = 3.26

Conservative $F_{.99}$ (1, 7) =12.25

Conservative $F_{.90}$ (1,7) = 3.59

* Conventional $p < .01$

@@ Conservative $p < .01$

@ Conservative $p < .10$

a. Simple main effects analysis of A x B interaction is shown in Table 15a.

Table 15a

Simple Main Effects Analysis of Variance for A x B Interaction of P3 Component (Fz Location)

Source of Variation	SS	df	MS	F
A (Treatment) at B (Feedback)				
A at b_1 (Correct)	341.40	3	113.80	5.19 *
A at b_2 (Under)	971.32	3	323.77	14.76 *
A at b_3 (Over)	623.01	3	207.67	9.47 *
B (Feedback) at A (Treatment)				
B at a_1 (Narrow)	82.03	2	41.02	1.87
B at a_2 (Middle)	188.18	2	94.09	4.29 *
B at a_3 (Wide)	538.66	2	269.33	12.28 *
B at a_4 (Control)	5.24	2	2.62	.12

For actual determination of error term, see page 93.

* $p < .05$

Table 16

Analysis of Variance for P3 Component (Pz Location) for Correct, Under, and Overestimation Feedback Signals under Narrow, Middle, Wide, and Control Treatment Conditions

Source of Variation	SS	df	MS	F
A Treatment)	2039.39	3	679.80	27.99 * @@
A x R (Replication)	510.05	21	24.29	
B (Feedback)	40.40	2	20.20	.95
B x R	299.20	14	21.37	
A x B [a]	370.96	6	61.83	4.13 * @
A x B x R	628.29	42	14.96	
R	1747.90	7	249.70	

a. Simple main effects analysis of A x B interaction is shown in Table 16a

Conventional $\underline{F}_{.99}$ (3,21) = 4.87 *conventional $\underline{p} < .01$
Conventional $\underline{F}_{.99}$ (6,42) = 3.26

Conservative $\underline{F}_{.99}$ (1, 7) =12.25 @@conservative $\underline{p} < .01$
Conservative $\underline{F}_{.90}$ (1, 7) = 3.59 @conservative $\underline{p} < .10$

Table 16a

Simple Main Effects Analysis of Variance for A x B Interaction of P3 Component (Pz Location)

Source of Variation	SS	df	MS	F
A (Treatment) x B (Feedback)				
A at b_1 (Correct)	802.31	3	267.44	17.88 *
A at b_2 (Under)	948.24	3	316.08	21.13 *
A at b_3 (Over)	659.40	3	219.80	14.69 *
B (Feedback) x A (Treatment)				
B at a_1 (Narrow)	137.65	2	68.82	4.60 *
B at a_2 (Middle)	6.11	2	3.05	.20
B at a_3 (Wide)	256.65	2	128.32	8.58 *
B at a_4 (Control)	11.61	2	5.81	.39

For actual derivation of error term, see page 93.

* $p < .05$

Component P4 also displayed interesting inter-cortical variation. P4, as well as the peak-to-peak measure, N1-P4, was distinctly parietal maximum, dropping 15% in magnitude at Cz and almost 45% at Fz. Unlike P3, the experimental manipulations were most consequential with the same Pz electrode. The frontal recording exhibited only treatment main effects, $\underline{F}$ (3,21) = 5.93, conventional $\underline{p} < .01$, conservative $\underline{p} < .05$, the irrelevant stimuli significantly abating N1-P4 magnitude. Neither the degree of task relevant information nor the type of feedback modified the peak-to-peak waveform. Conversely, a significant parietal treatment x stimulus interaction was found, $\underline{F}$ (6,42) = 4.47, conventional $\underline{p} < .01$, conservative $\underline{p} < .10$. Again the absence of task relevancy significantly attenuated N1-P4 amplitude. In addition to this factor, unpredictability also came into play. When confirmation was most unlikely (narrow window), N1-P4 was significantly enhanced over the times when it was either moderately (middle window) or highly likely (wide window). Disconfirmation did not adhere to the same trend, significantly augmenting N1-P4 more than confirming feedback under the middle and wide window conditions, in both instances the under-correct estimation difference being significant, the over-correct estimation difference just failing to attain significance.

From these topographical results it appears that P3 and P4 may represent quite distinct phenomena. The parietal P4 showed experimental results not seen for P3, while the frontal P3 was quite unlike the frontal P4. The summary of the analysis of variance for the parietal P4 data is shown in Table 17, and the simple main effects testing in Table 17a.

Table 17

Analysis of Variance for P4 Component (Pz Location) for Correct, Under, and Overestimation Feedback Signals under Narrow, Middle, Wide, and Control Treatment Conditions

Source of Variation	SS	df	MS	F
A (Treatment)	1216.24	3	405.41	11.40 * @@
A x R (Replication)	746.88	21	35.57	
B (Feedback)	51.19	2	25.59	4.15
B x R	86.42	14	6.17	
A x B [a]	342.55	6	57.09	4.47 * @
A x B x R	536.20	42	12.77	
R	793.78	7	113.40	

a. Simple main effects of A x B interaction is shown in Table 17a.

Conventional $\underline{F}_{.99}$ (3,21) = 4.87	*conventional $\underline{p}$ < .01
Conventional $\underline{F}_{.99}$ (6,42) = 3.26	
Conservative $\underline{F}_{.95}$ (1, 7) = 5.59	@@conservative $\underline{p}$ < .05
Conservative $\underline{F}_{.90}$ (1, 7) = 3.59	@conservative $\underline{p}$ < .10

Table 17a

Simple Main Effects Analysis of Variance for A x B Interaction of P4 Component (Pz Location)

Source of Variation	SS	df	MS	F
A (Treatment) x B (Feedback)				
A at b_1 (Correct)	545.87	3	181.96	14.25 *
A at b_2 (Under)	555.30	3	185.10	14.49 *
A at b_3 (Over)	458.21	3	152.74	11.96 *
B (Feedback) at A (Treatment)				
B at a_1 (Narrow)	166.96	2	83.48	6.54 *
B at a_2	78.76	2	39.38	3.08 *
B at a_3	140.24	2	70.12	5.49 *
B at a_4	6.56	2	3.28	.26

For actual derivation of error term, see page 93.

* $p < .05$

It appears that P4 is an index of further re-evaluation of earlier formed hypotheses or plans of action, perhaps representing a simultaneous reintegration and recall of diverse sources of information. It could represent a transfer of information obtained from frontal successive processing (frontal P3) and shifted to the posterior zones (parietal P4) which is vaguely analagous to Nauta's (1972) "flow of information" model. Very recently, Lesèvre and Renaud (1976) presented evidence supporting these findings -- their positive wave becoming more and more posterior with time. Wilkinson and Ashby (1974) also speak of a "wave of positivity" reporting that measurements P300, P400, and even P500 shared a large extent of common variance. In Experiment 1-1, the correlation between P3 and P4 employing the raw data from all conditions and subjects for the vertex recordings was .68,providing partial support for the notion that P3 and P4 are not entirely independent. In relation to the posterior dominance of P4, Stuss et al. (1976) suggested that it may reflect a resetting of a primary sensory area since their task involved visual concept learning. With time estimation it is difficult to speculate about resetting of primary sensory areas,yet P4 is still parietal maximum. It could be however that time estimation takes place in parietal regions.

Post-feedback resolution, like P4, continued as a central-posterior activity. It was most positive at Pz, approaching the baseline by an additional 25% at Cz and another 65% at Fz, significant treatment effects being indicated parietally, $\underline{F}$ (3,21) = 5.85, conventional $\underline{p} < .01$, conservative $\underline{p} < .05$. Post-hoc testing again discerned the significant role of absence of feedback relevancy. The resolution of relevant feedback information was not completed until some time later than the end of the sweep employed in this study. The continuation of positivity following P4 provides further evidence of the possibility of a prolonged wave of positivity moving from frontal into parietal areas.

In summary, Experiment 1-1 attempted to investigate the effects of surprisal and degree of task relevant information of confirming and disconfirming feedback on performance in a time estimation task and on various components of the evoked potential. When feedback was task relevant, errors of estimation significantly decreased, while physiologically the positive components of the evoked potential (P2, P3, P4) were significantly enhanced, this particularly being the case for the later components, P3 and P4. P3, especially at frontal and central locations, manifested a complex relationship with feedback related to its task relevant information content. Disconfirming feedback evoked larger P3 peaks than confirming when it contained greater amounts of task relevant information. When the degree of task relevant information was slightly in favour of confirmation, although it evoked slightly greater P3 amplitude responses than the less informative disconfirming feedback, the difference was not significant. The correlation however between the mean P3 amplitude at Cz and task relevant information content was extremely high at .92. The parietal P4 in some sense displayed effects similar to those of the frontal P3. At this stage of analysis the independence of P3 and P4 cannot be asserted with any degree of authority.

Experiments 3-1 and 3-2

In Experiment 1-1 with relevant feedback signals, the role of surprisal and degree of task relevant information was confounded. Experiments 3-1 and 3-2 were designed to separate out the effects of both. In Experiment 3-1, three conditions were run: QUAN, in which feedback were quantitative, informing the subject of correct, under, and overestimations; QUAL-HI, in which feedback simply informed the subject of correct or incorrect estimations, two LEDs being employed for the latter to render the amount of stimulus surprisal equal to QUAN, but the degree of task relevant information for disconfirming stimuli varying; and CONT-HI, a control condition in which stimuli were task irrelevant occurring according to a probability schedule in accordance with QUAN and QUAL-HI, again stimulus surprisal being equal but degree of task relevant information in each stimulus being considerably reduced, to zero bits.

Experiment 3-1 thus manipulated task relevant information content holding surprisal constant. Experiment 3-2 manipulated both, holding the amount of task relevant information constant and manipulating surprisal in one instance and doing the reverse in another. The data from the confirming and one of the disconfirming feedback stimuli in the QUAN and QUAL-HI conditions were re-analyzed to examine the role of varying task relevant information content in a stimulus when its degree of surprisal was held constant. They in turn were compared to QUAL-LO, a condition in which the amount of task relevant information for the disconfirming stimulus equalled that of QUAL-HI, but its surprisal was lower. In QUAN, QUAL-HI, and QUAL-LO, the amount of task relevant information and surprisal in the confirming stimulus were equal. In a fourth condition CONT-LO, the ratio of confirming to disconfirming stimuli equalled QUAL-LO, thus controlling for surprisal effects but the amount of task relevant information in the stimuli was zero bits since the stimuli had no feedback qualities but were contingent rather on a random computer generated probability schedule.

The behavioural analysis for Experiment 3-1 indicated the control condition (CONT-HI) was significantly associated with greater errors of estimation than in trials in which task relevant feedback was provided, $\underline{F}$ (2,14) = 5.75, conventional $\underline{p} < .05$, conservative $\underline{p} < .05$, replicating Experiment 1-1 findings. When the degree of task relevant information was reduced in the disconfirming feedback stimuli (QUAL-HI condition), absolute error in judgement increased by 11.3 ms from the fully informative quantitative (QUAN) feedback condition, this increase however not being statistically significant. Thus the more informative the stimuli, the greater is the ability of the subject to use this informative about past events for performance on future trials.

Experiment 3-2 pointed to an almost duplicate interpretation, $\underline{F}$ (3,21) = 3.01, conventional $\underline{p} < .06$, conservative $\underline{p} > .10$, with irrelevant stimuli again being associated with longer time estimations. The difference in time estimation error between the QUAL-HI and QUAL-LO conditions was less than 1 ms. The mean error scores for Experiments

3-1 and 3-2 are combined and presented as Figure 13. The analyses of variance for the two experiments are shown in Tables 18 and 19.

The physiological data recorded at the vertex (Cz) revealed no significant pre-stimulus CNV shifts in Experiment 3-1, an indication that regardless of the average degree of task relevant information of the stimuli in the various conditions, prior preparation to process this information appears to be unaffected. Similarly in Experiment 3-2, prior CNV was unaltered by the demands of the respective conditions. It is interesting to note that control conditions were associated with fairly substantial prior CNV amplitude. A schematic representation of the mean data of the components of the evoked potential for both experiments is illustrated in Figure 14.

Component N1, as was the case in Experiment 1-1, had a tendency to show some conditional relationships although they were not significant. In Experiments 3-1 and 3-2 disconfirming signals triggered an approximate -1.5 to -2.0 μV increase in N1 amplitude, suggesting that because of the consistency across days (Day 1 and Day 3), the change in N1 with disconfirmation is more than simply a random, chance phenomenon. Adams (1968) has presented evidence that subjects adopt a uniform expectation of being correct, overlooking objective odds to the contrary. In this experiment then, even though disconfirmation was more frequent than confirmation, being informed of incorrect estimations via the feedback diodes might still have been unexpected. Hillyard et al. (1973) and Simson et al. (1976) have shown that when subjects are attentive to unexpected

Figure 13. Mean absolute time estimation error as a function of informational qualities of feedback (Experiments 3-1 and 3-2).

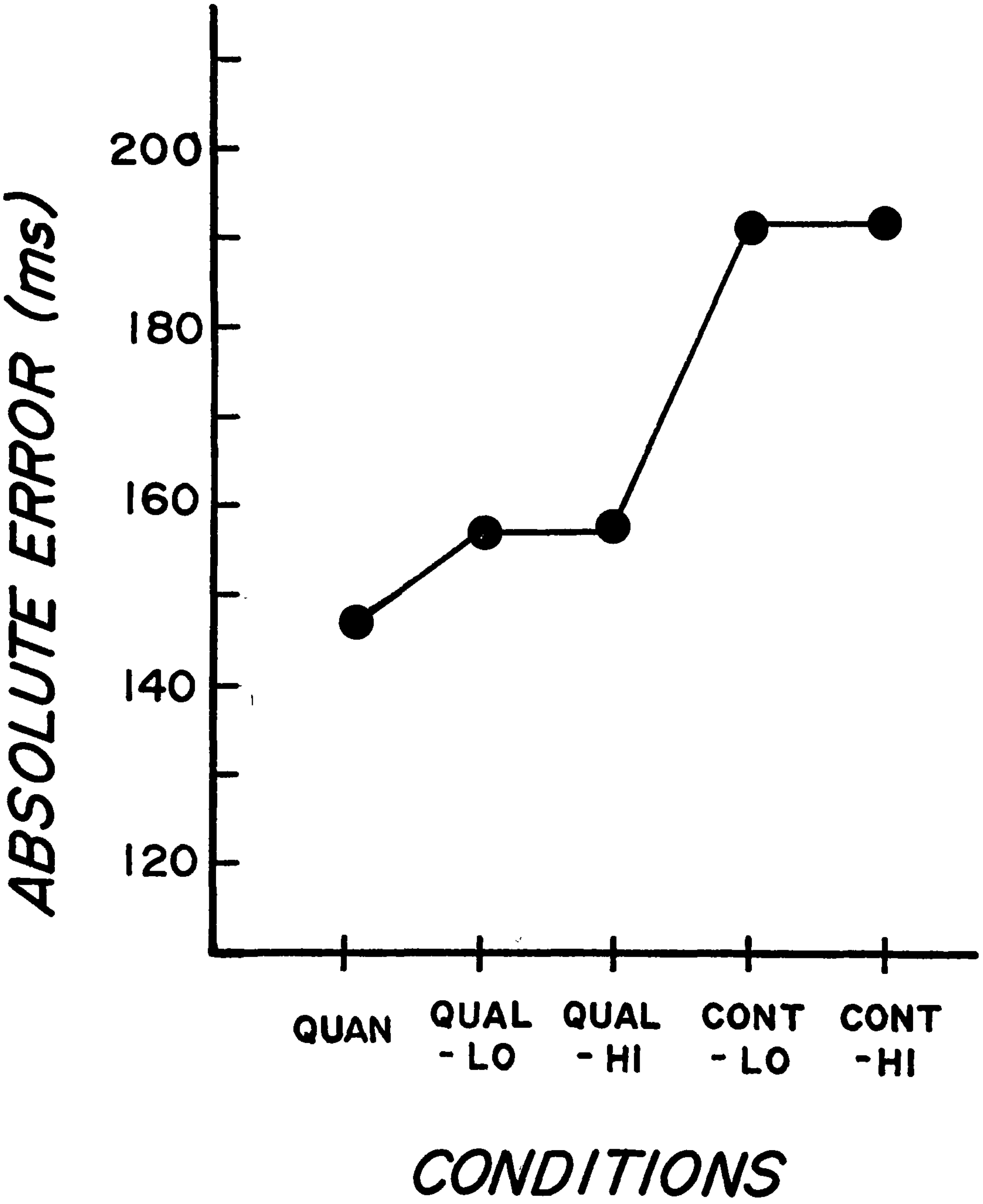

ABSOLUTE ERROR (ms)
200
180
160
140
120
QUAN
QUAL - LO
QUAL - HI
CONT - LO
CONT -HI
CONDITIONS

Table 18

Analysis of Variance of Behavioural Data for Experiment 3-1, under QUAN, QUAL-HI, and CONT-HI Treatment Conditions

Source of Variation	SS	df	MS	F
Between Subjects				
R (Replications)	29146.97	7	4136.85	
Within Subjects				
A (Treatment)	8793.01	2	4396.50	5.75 * @
T x R	10696.80	14	764.06	

Conventional $F_{.95}$ (2, 14) = 6.51 * conventional $p < .05$

Conservative $F_{.95}$ (1, 7) = 5.59 @ conservative $p < .05$

Table 19

Analysis of Variance of Behavioural Data for
Experiment 3-2, under QUAN, QUAL-HI, QUAL-LO,
and CONT-LO Treatment Conditions

Source of Variation	_SS_	_df_	_MS_	_F_
Between Subjects				
R (Replications)	42007.07	7	6001.01	
Within Subjects				
A (Treatment)	8905.50	3	2968.50	3.01 * @
A x R	20677.32	21	984.63	

Conventional $\underline{F}_{.95}$ (3,21) = 3.06

Conservative $\underline{F}_{.90}$ (1, 7) = 3.59

* conventional $\underline{p} < .06$

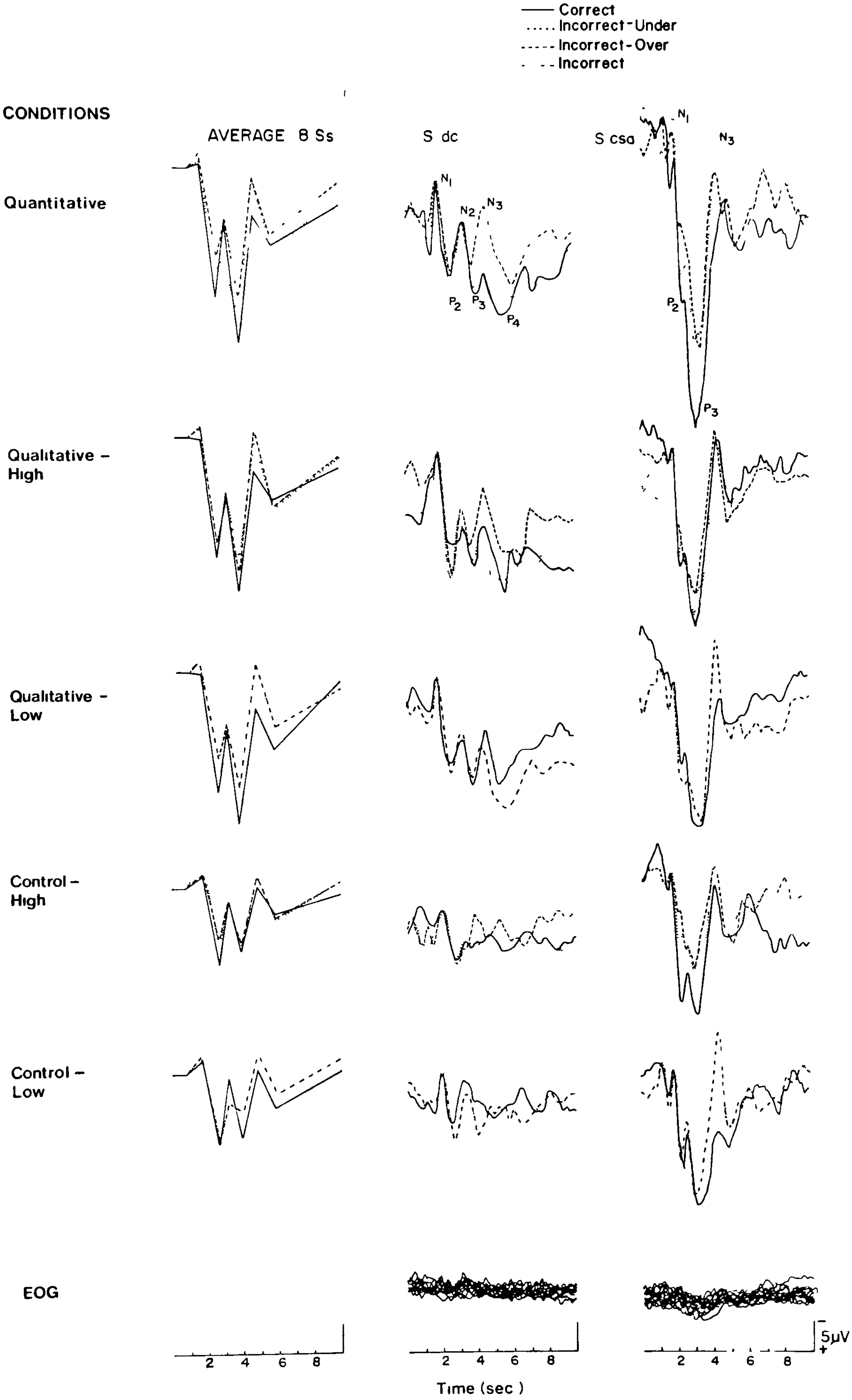
@ conservative $\underline{p} > .10$

events, N1 markedly increased, it perhaps reflecting the initial stages of the decision complex. Subjects then may have been more responsive to disconfirming feedback than confirming, it triggering a host of informational processing demands. Whatever the underlying mechanism, the possible correct-incorrect bias will have to be taken into account when considering other components.

Magnitude of P2 continued to prove sensitive to an absence of relevant feedback quality. In Experiment 3-1, significant treatment differences were found, $F(2,14) = 10.70$, conventional $p < .01$, conservative $p < .05$, post-hoc testing indicating that both the QUAN and QUAL-HI conditions, i.e., conditions in which feedback contained at least some degree of task relevant information, significantly enhanced P2 more than the control (CONT-HI) condition. QUAN and QUAL-HI effects on P2 did not significantly differ nor were any P2 differences noted between confirming and disconfirming feedback main effects. Thus as soon as stimuli take on a task relevant feedback role, the amplitude of P2 more than doubles. Adding on still more task relevant information to a feedback signal has little effect on P2.

Experiment 3-1 held surprisal constant while manipulating task relevant information content; Experiment 3-2 manipulated both. The results of the latter experiment demonstrate clearly that changes in the extent to which signals are task relevant or not, rather than changes in stimulus surprisal were responsible for variation in P2 magnitude. The analysis of variance for treatment main effects was once again significant,

Figure 14. Schematic representation of the Cz evoked potential waveform as a function of the independent variables of Experiments 3-1, and 3-2. Also included are sample records from two subjects (DC and CSA).



—— Correct
..... Incorrect-Under
----- Incorrect-Over
- - - Incorrect
CONDITIONS
AVERAGE 8 Ss
S dc
S csa
Quantitative
Qualitative - High
Qualitative - Low
Control - High
Control - Low
EOG
N_1
N_2
N_3
P_2
P_3
P_4
2
4
6
8
Time (sec)
5μV
-
+

F (3,21) = 7.94, conventional $p < .01$, conservative $p < .05$. P2 was significantly attenuated only when stimuli were irrelevant. When the degree of task relevant information was held constant, and surprisal manipulated (QUAL-HI versus QUAL-LO), no corresponding P2 effect was seen. Similarly the failure to find confirming-disconfirming main effects was again replicated. The data are thus very consistent in depicting P2 serving as an early index of a filtering process -- task relevant feedback require further cognitive processing while irrelevant stimuli due to their simple structure demand far less cortical involvement. The analysis of variance for Experiment 3-1 is presented in Table 20 and for Experiment 3-2 in Table 21.

The second negative peak, N2, continued as well to mimic these findings. Both Experiments 3-1 and 3-2 indicated that control, irrelevant stimuli evoked N2 waves that were significantly more negative than relevant feedback stimuli, F (2,14) = 12.68, conventional and conservative $p < .01$ for Experiment 3-1 and F (3,21) = 11.98, conventional $p < .01$, conservative $p < .05$, for Experiment 3-2. N2 in fact remained well below baseline (negative valence upwards) when the stimuli took on task relevant feedback qualities, likely due to the positive pull of P2 and P3 (Adams and Benson, 1973; Friedman et al., 1973; Naatanen, 1967, 1975). This again hints at a long lasting positive wave (Naatanen, 1975; Wilkinson and Ashby, 1974). The increased N2 negativity seen with irrelevant stimuli might well have been due to its small positive influence on P2 since P2-N2 peak-to-peak differences failed to reveal any significant treatment main effects in either experiment.

Table 20

Analysis of Variance for P2 Component (Cz Location) for Correct, Under, and Overestimation Feedback Signals under QUAN, QUAL-HI, and CONT-HI Treatment Conditions

Source of Variation	SS	df	MS	F
A (Treatment)	1037.25	2	518.62	10.70 * @
A x R (Replication)	678.56	14	48.47	
B (Feedback)	244.91	2	122.45	3.60
B x R	476.48	14	34.03	
A x B	54.79	4	13.70	.88
A x B x R	436.72	28	15.60	
R	2356.97	7	336.71	

Conventional $F_{.99}$ (2,14) = 6.51

Conservative $F_{.95}$ (1, 7) = 5.59

* conventional $p < .01$

@ conservative $p < .05$

Table 21

Analysis of Variance for P2 Component (Cz Location), Experiment 3-2, for Correct and Incorrect Feedback Signals under QUAN, QUAL-HI, QUAL-LO, and CONT-LO Treatment Conditions

Source of Variation	SS	df	MS	F
A (Treatment)	749.52	3	249.84	7.94 * @
A x R (Replication)	660.78	21	31.47	
B (Feedback)	234.23	1	234.23	3.54
B x R	463.64	7	66.23	
A x B	41.73	3	13.91	.57
A x B x R	516.98	21	24.62	
R	2136.92	7	305.27	

Conventional $F_{.99}$ (3,21) = 4.87

Conservative $F_{.95}$ (1, 7) = 5.59

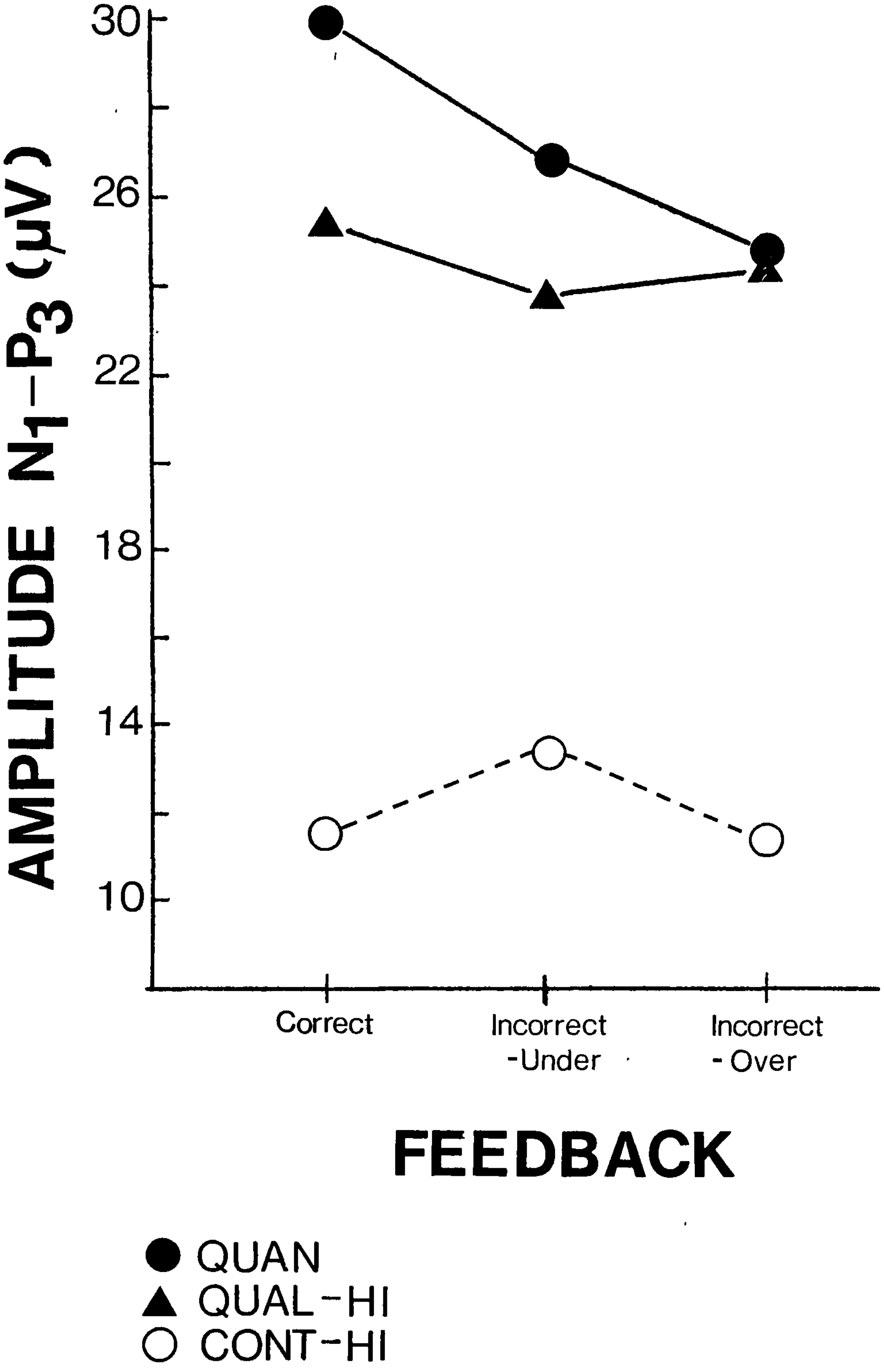
* conventional $p < .01$

@ conservative $p < .05$

In Experiment 1-1, with the narrow window condition, disconfirming feedback evoked slightly smaller P3 amplitude than confirming, the difference however was not significant. On the other hand, a very high correlation (.92) was found between the amount of task relevant information in a stimulus and the consequent amplitude of P3. Taking this same window size (making confirmation a more unusual event than disconfirmation) and manipulating the degree of task relevant information found in disconfirming feedback, it was noted that only when stimuli were completely void of relevance (CONT-HI condition) did P3 amplitude significantly decrease, $\underline{F}$ (2,14) = 27.33, conventional and conservative $\underline{p} < .01$. The interaction of treatment x type of feedback was not significant, $\underline{F}$ (4,28) = 1.30, conventional and conservative $\underline{p} > .10$, indicating that individual variation in task relevant informational content did not effect P3. The analysis of variance for the P3 component in Experiment 3-1 is shown in Table 22. The mean N1-P3 amplitude for the various conditions are plotted as Figure 15. While the analysis of variance failed to indicate significant P3 differences between conditions that varied in degree of task relevant information, the correlation based on these scores and those from Experiment 3-2 demonstrated a good deal of co-variance, $\underline{r} = .88$.

Experiment 3-2 in addition to manipulating relevant information content also examined the role of stimulus surprisal. It, like Experiment 3-1, showed that only irrelevant stimuli significantly attenuated P3 amplitude, $\underline{F}$ (3,21) = 25.21, conventional and conservative

Figure 15. N1-P3 mean amplitude (Cz location) plotted as a function of decision outcome and treatment condition of Experiment 3-1.



AMPLITUDE N_1-P_3 (µV)
30
26
22
18
14
10
Correct
Incorrect -Under
Incorrect - Over
FEEDBACK
● QUAN
▲ QUAL-HI
○ CONT-HI

Table 22

Analysis of Variance for P3 Component (Cz Location), Experiment 3-1, for Correct, Under , and Overestimation under QUAN, QUAL-HI, and CONT-HI Treatment Conditions

Source of Variation	SS	df	MS	F
A (Treatment)	3798.08	2	1899.04	27.33 * @
Ax R (Replication)	972.81	14	69.49	
B (Feedback)	180.94	2	90.47	1.57
B x R	805.96	14	57.57	
A x B	132.24	4	33.06	1.30
A x B x R	710.23	28	25.37	
R	3158.15	7	451.16	

Conventional $F_{.99}$ (2,14) = 6.51 * conventional $p < .01$

Conservative $F_{.99}$ (1,7) = 12.25 @ conservative $p < .01$

$p < .01$ (Table 23). Disconfirming feedback that varied in either degree of surprisal or task relevant information did not significantly alter P3 amplitude. The disconfirming feedback signals that varied in surprisal but contained the same amounts of task relevant information evoked almost exactly equal P3 components while slight although not significant differences were found (as was indicated in Experiment 3-1) between disconfirming feedback that were equally surprising but varied in task relevant information content. The correlation between the mean P3s evoked by the various stimuli and surprisal was .31. The means for Experiment 3-2 are illustrated in Figure 16.

Tueting et al. (1971) proposed that the primary correlate of P3 was uncertainty or unexpectedness of occurrence of a stimulus. Squires et al. (1973a) for example suggested that P3s following disconfirming feedback were larger only because those signals were less frequent than confirming. The present data however suggest that unexpectedness or "surprisal" as defined in this study, by and in itself, is not enough to explain P3. Although the ANOVAs did not always indicate it, the correlational data supports the notion that P3 provides a reliable index of the degree of task relevant information contained in the stimulus. Sutton et al. (1965) and Tueting et al. (1971) found their same relationship between rarity of event occurrence and subsequent P3 amplitude even when the subject was certain of the outcome of the event, i.e., even when he was able to predict a rare event, which might be evidence in support of the role of surprisal.

Figure 16. N1-P3 mean amplitude (Cz location) plotted as a function of decision outcome and treatment condition of Experiment 3-2.

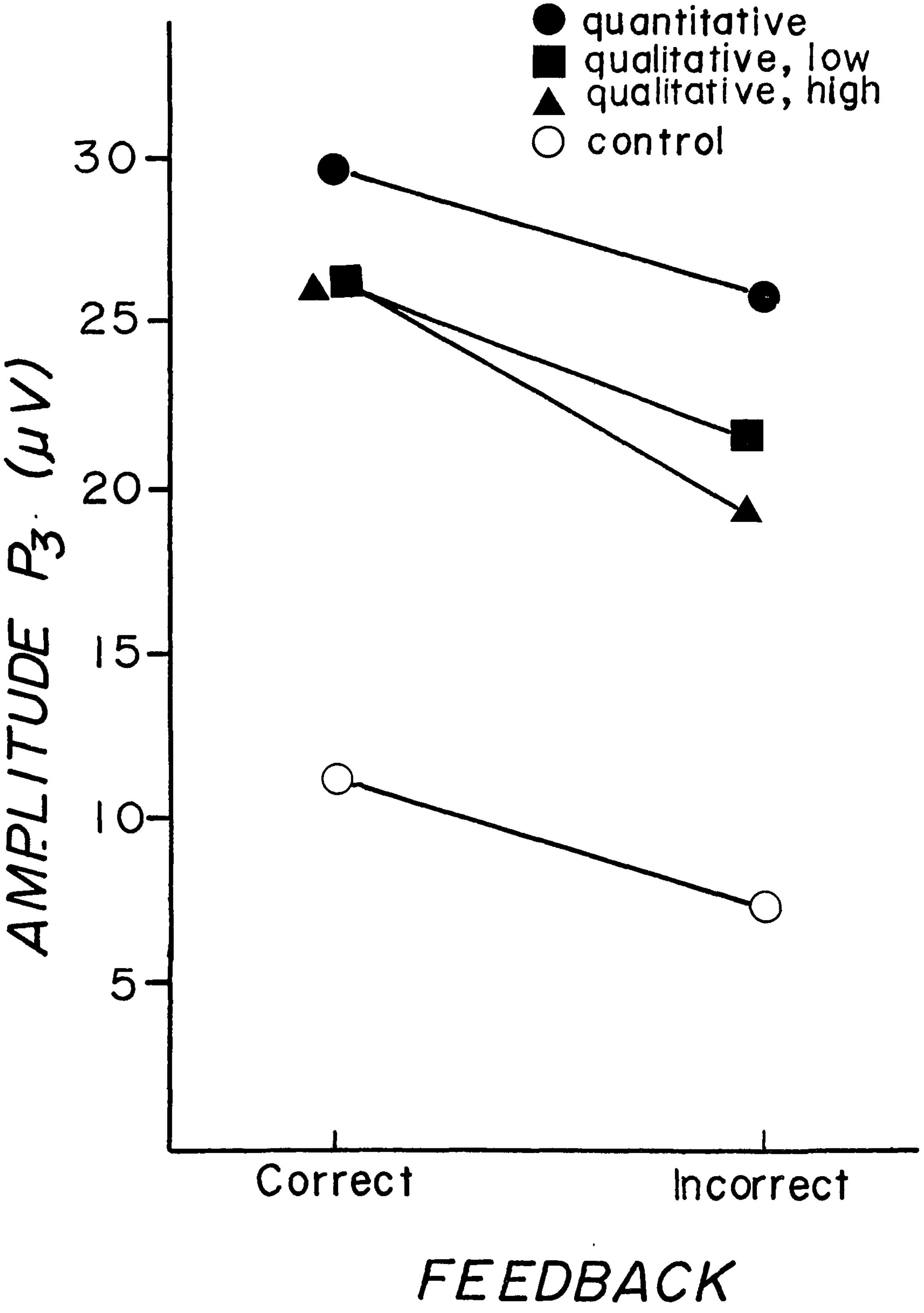

● quantitative
■ qualitative, low
▲ qualitative, high
○ control
AMPLITUDE P_3 (μV)
30
25
20
15
10
5
Correct
Incorrect
FEEDBACK

Table 23

Analysis of Variance for P3 Component (Cz Location), Experiment 3-2, for Correct and Incorrect Feedback Signals under QUAN, QUAL-HI, QUAL-LO, and CONT-LO Treatment Conditions

Source of Variation	SS	df	MS	F
A (Treatment)	3151.77	3	1050.59	25.21 * @
A x R (Replication)	875.31	21	41.68	
B (Feedback)	410.04	1	410.04	3.69
B x R	778.81	7	111.26	
A x B	25.21	3	8.40	.32
A x B x R	558.38	21	26.59	
R	2551.54	7	364.51	

Conventional $F_{.99}$ (3,21) = 4.87

Conservative $F_{.99}$ (1, 7) = 12.25

* conventional $p < .01$

@ conservative $p < .01$

Component N3 like N2 was likely influenced by the positive components, P3 and P4. Although irrelevant stimuli evoked more negative N3 peaks than their counterpart, task relevant feedback, in Experiment 3-1 the difference just failed to reach significance, F (2,14) = 3.64, conventional $p < .05$, conservative $p < .10$. The difference however attained significance in Experiment 3-2, F (3,21) = 4.41, conventional $p < .01$, conservative $p < .10$. Disconfirmation was as well associated with significantly greater negativity than confirmation in Experiment 3-2, F (1,7) = 14.22, conventional and conservative $p < .01$ but not in Experiment 3-1, F (2,14) = 4.74, conventional $p < .05$, conservative $p < .10$. The disconfirming influences might be related to prior P3 differences since there it (disconfirmation) tended to evoke slightly smaller peaks. It follows then that the peak-to-peak measure P3-N3 would fail to demonstrate type of feedback differences. Once again relevant feedback was associated with below baseline N3 waves pointing to the attenuation of negative components in favour of positive ones.

Analysis of the P4 data in both experiments strongly back up the P3 findings with respect to relevancy of the stimulus. When stimuli were task irrelevant, sharp, significant attentuation of P4 was apparent, F (2,14) = 13.19, conventional and conservative $p < .01$ and F (3,21) = 9.70, conventional $p < .01$, conservative $p < .05$ in Experiments 3-1 and 3-2 respectively. Aside from the instances when stimuli were completely irrelevant, additional degrees of task relevant information had little effect on P4. Confirming and disconfirming feedback in spite of the extra degree of relevant information in the former evoked almost identical P4 components.

If P4 is indeed an index of further neural processing or utilization of feedback (Stuss et al., 1976), disconfirmation because of its call for re-evaluation and re-programming may be able to overcome informational loading demands. Ordinarily when an event is repetitive, the cortical response rapidly declines or habituates (Ritter et al., 1968; Sokolov, 1963) indicating that the stimulus information has become redundant. With disconfirming signals at least, it appears that the Sokolovian model breaks down.

Post-feedback resolution continued in the same pattern as P2, P3, and P4. With relevant feedback signals, electrical activity remained significantly more below or close to baseline than when the stimuli did not inform the subject of her past performance, F (2,14) = 4.81, conventional $p < .05$, conservative $p < .10$ in Experiment 3-1, and F (3,21) = 4.84, conventional $p < .01$, conservative $p < .10$ in Experiment 3-2.

Different cortical regions were allied to specific experimental influences with particular components of the evoked potential on Day 1. Experiments 3-1 and 3-2 further accentuate these differences.

CNV remained largest (most negative) parietally decreasing by 41% centrally and another 76% frontally in Experiment 3-1 and 49% and another 86% respectively in Experiment 3-2. Further analysis of parietal CNV dominance comes from the results of the across-scalp analyses of variance. At Cz there was a nonsignificant tendency for the control condition to be linked with stunted CNV. Parietally both Experiments 3-1 and 3-2 manifested a significant increase in negativity in CNV prior to occurrence of task relevant feedback, F (2,14) = 11.91, conventional

$p < .01$, conservative $p < .05$, and $F(3,21) = 5.69$, conventional $p < .01$, conservative $p < .05$ respectively. Frontally almost no difference was found between the treatment conditions. That prior CNV was largest parietally is in keeping with the idea of priming of the primary zones (occipital lobes) for reception of a visual stimulus. Simson et al. (1976) have presented topographical maps indicating that N1 is heavily posterior maximum.

The late positive component, P3, continued to be widespread, being largest parietally dropping 10% centrally and another 25% frontally in both Experiments 3-1 and 3-2.

Relevancy/irrelevancy continued to play its familiar role. Contrary to the P2 and N1-P2 trends, the effects of P3 were widely felt, the treatment main effects being significant frontally, $F(2,14) = 18.66$, conventional and conservative $p < .01$ and $F(3,21) = 16.22$, conventional and conservative $p < .01$ in Experiments 3-1 and 3-2 respectively, and parietally $F(2,14) = 44.15$, conventional and conservative $p < .01$ and $F(3,21) = 38.59$, conventional and conservative $p < .01$ in Experiments 3-1 and 3-2 respectively . Testing following *post-hoc* procedures indicated that for Experiment 3-1 for all scalp locations, P3 was significantly attenuated for the control condition. There was a tendency for P3 amplitude to vary directly with task relevant information content both at Pz and Fz, there perhaps being a hint of a greater disconfirming influence frontally than parietally.

Experiment 3-2 in addition to showing the decremental influence of irrelevant stimuli and the covariation between P3 amplitude and task relevant information content,indicated that when disconfirming feedback was equivalent in task relevant informational content but varied in surprisal (conditions QUAL-HI and QUAL-LO), significant differences in P3 were not found either frontally or parietally.

P4 like P3 was parietal maximum. P3 however manifested large frontal effects; P4 did not. It dropped 10-15% centrally and 60% frontally in the two Day 3 experiments. As expected,irrelevancy took on its traditional role, control stimuli being associated with a two- to three- and sometimes four- fold decay in amplitude parietally. No differences were found between the influences of confirming and disconfirming feedback or in other words, in the degree of task relevant information of feedback signals.

Experiments 2-1 and 2-2

Experiment 2-1 was designed to study the influence of various incentives on the behavioural and physiological measures. Three types of payoffs providing for three incentive conditions were utilized: a positive incentive in which 10¢ was awarded for correct estimations with no loss for incorrects, a negative incentive in which the opposite was true, no award for correct estimations but a 10¢ loss was subtracted for incorrects, and a positive and negative incentive in which 10¢ was awarded for corrects and a 10¢ loss subtracted for incorrects. A no incentive condition served as a control condition.

In Experiment 2-2 the monetary value attached to a particular stimulus served as an independent variable. Qualitative feedback was employed, subjects therefore being informed that an estimation was correct or incorrect without further differentiation in the case of incorrect estimations. Two LEDs were nevertheless used for disconfirmation, the selection of the appropriate disconfirming diode being determined by a random equal probability computer program. In the equal value condition, 10¢ was awarded for correct estimations and 10¢ subtracted for incorrect estimations (i.e., 10¢ lost upon occurrence of either disconfirming LED). In the unequal value condition, 10¢ was again awarded for correct estimations, 20¢ was lost when one of the incorrect LEDs was flashed, and no money lost when the other incorrect LED was flahsed. A one-way ANOVA thus was used to analyze the physiological data.

In both experiments the window was adjusted to provide for an error rate of of 66.7%. Thus all three LEDs occurred with equal likelihood.

Figure 17 plots the absolute mean time estimation error across all the conditions on Day 2. The analysis of variance indicated that neither the incentive nor value conditions had a significant effect on time estimation. The question raised by the failure to find a significant difference in errors of estimation between incentive and no incentive conditions is if the monetary payoffs were actually effective in increasing the level of motivation of the subjects. From post-experimental subjective reports most subjects did mention that they did indeed "try harder". The effect of the additional incentive provided by the various payoffs may have carried over to the no incentive condition.

Figure 17. Mean absolute time estimation error as a function of monetary incentive and value placed on a particular stimulus, Experiments 2-1 and 2-2.

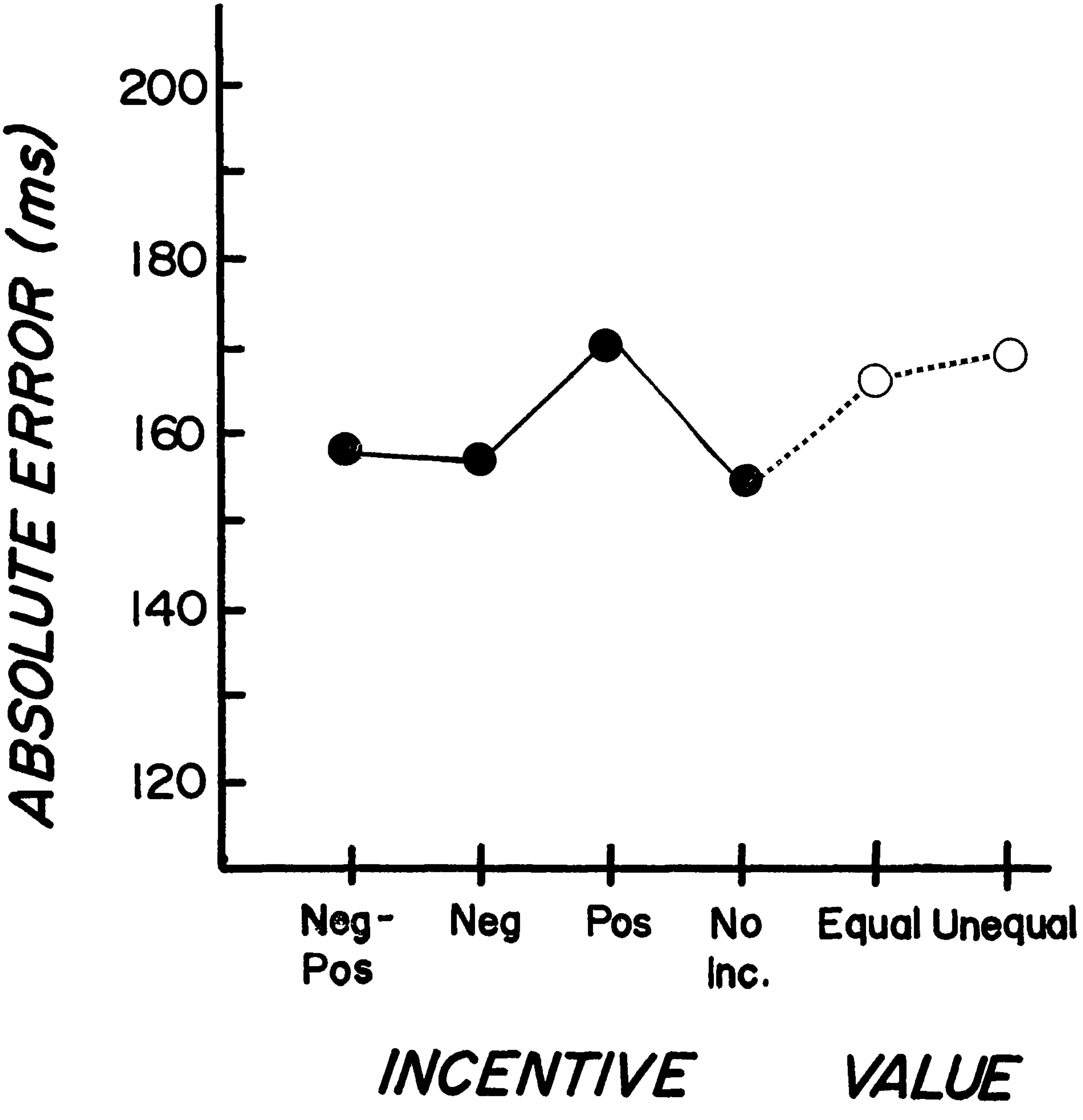

ABSOLUTE ERROR (ms)
200
180
160
140
120
Neg-Pos
Neg
Pos
No Inc.
Equal
Unequal
INCENTIVE
VALUE

Table 24

Analysis of Variance of Behavioural Data for Experiment 2-1, under Negative and Positive, Negative, Positive, and two No Incentive Treatment Conditions

Source of Variation	*SS*	*df*	*MS*	*F*
Between Subjects				
R (Replications)	86611.61	7	12373.09	
Within Subjects				
A (Treatment)	1634.60	4	408.65	.37
A x R	30965.74	28	1105.92	

Table 25

Analysis of Variance of Behavioural Data for Experiment 2-2, under Equal and Unequal Value Treatment Conditions

Source of Variation	SS	df	MS	F
Between Subjects				
R (Replications)	22180.46	7	3168.64	
Within Subjects				
A (Treatment)	44.22	1	44.22	.03
A x R	11418.64	7	1631.23	

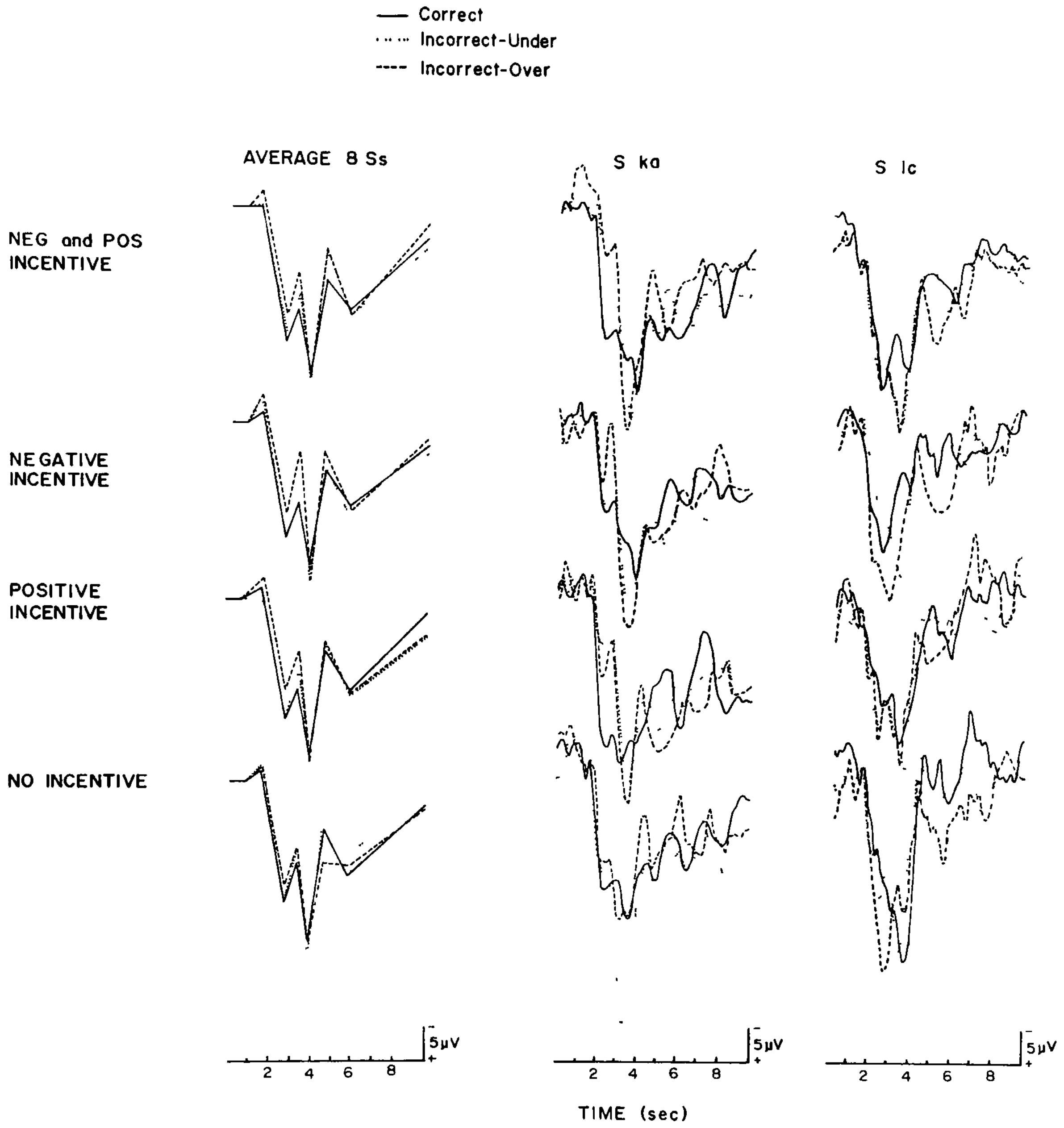
The physiological data largely is in accord with the behavioural findings. Figure 18 presents a schematic view of the mean waveform and actual records from two subjects for Experiment 2-1.

In Experiment 2-1, incentive of any kind, including no incentive at all, had no significant effect on pre-stimulus CNV, N1, P2, or N2 amplitude. The component of prime interest, P3, also failed to show any significant modification. Regardless of the fact that incentive was positively or negatively slanted, balanced, or did not exist at all, changes in cognitive evaluation or cortical involvement remained unaffected, as evidenced by the failure to find component fluctuation. P3, thus, does not seem to be correlated with incentive, its amplitude being largely determined by those factors manipulated in Experiments 1-1, 3-1, and 3-2. The P3 means of the various conditions are illustrated in Figure 19.

A final possible correlate of P3 is value. When the monetary value placed on a feedback stimulus equalled -20, -10, 0, or +10¢, no significant effect was again seen on any component of the evoked potential, including P3.

Unfortunately past research in the area of payoff incentive is limited (Jenness, 1972a,b; Paul and Sutton, 1972; Poon et al., 1974; Sutton et al., 1965). In these studies payoff was confounded with other

Figure 18. Schematic representation of the Cz evoked potential waveform as a function of monetary incentive (Experiment 2-1). Also included are sample records from two subjects, LC and KA.



Correct
Incorrect-Under
Incorrect-Over
AVERAGE 8 Ss
S ka
S lc
NEG and POS INCENTIVE
NEGATIVE INCENTIVE
POSITIVE INCENTIVE
NO INCENTIVE
5µV
2
4
6
8
TIME (sec)

Figure 19. Base-P3 mean amplitude (Cz location) as a function of decision outcome and monetary incentive, Experiment 2-1.

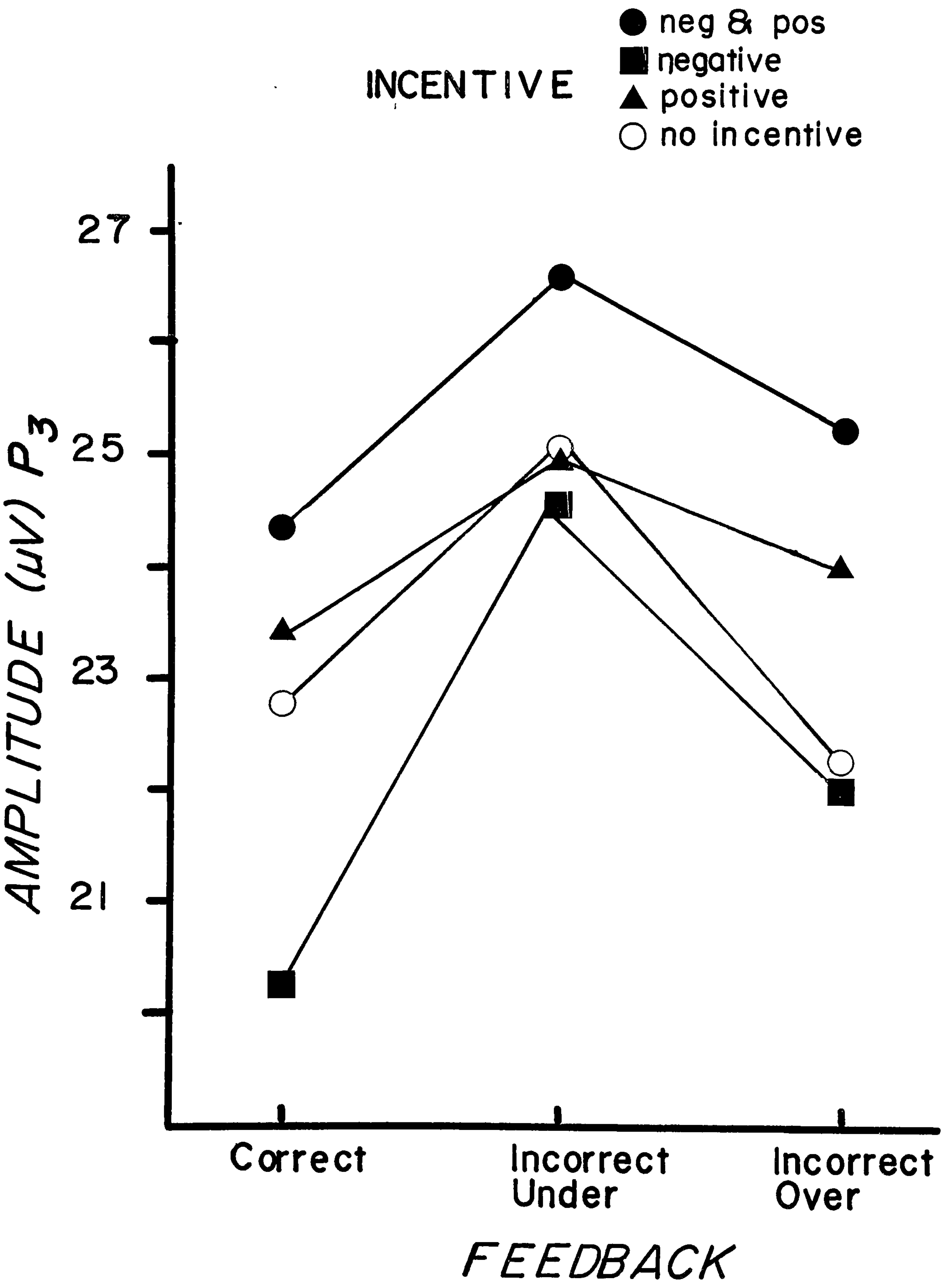

INCENTIVE
● neg & pos
■ negative
▲ positive
○ no incentive
27
25
23
21
AMPLITUDE (μV) P_3
Correct
Incorrect Under
Incorrect Over
FEEDBACK

Table 26

Analysis of Variance of the P3 Component (Cz Location) for Correct, Under, and Overestimation Feedback Signals Under Negative, Positive, Negative and Positive, and No Incentive Conditions

Source of Variation	SS	df	MS	F
A (Incentive)	143.71	4	35.28	1.12
A x R (Replication)	895.60	28	31.99	
B (Feedback)	99.49	2	49.74	.94
B x R	736.68	14	52.63	
A x B	42.40	8	5.30	.29
A x B x R	1021.06	56	18.26	
R	3678.44	7	525.49	

Table 27

Analysis of Variance of the P3 Component (Cz Location)
for Signals Associated with Different Monetary Value

Source of Variation	*SS*	*df*	*MS*	*F*
A (Value,Treatment)	55.15	5	11.03	.44
A x R (Replication)	870.62	35	24.87	
R	1538.95	7	219.85	

variables such as probability, which have been shown to affect P3 amplitude. This is believed to be the first study in which monetary payoffs were systematically manipulated independent of other variables. Sutton (personal communication with T. Picton, 1976) has recent evidence showing that in the feedback-guessing paradigm, the amplitude of P3 can be altered if the monetary value of the guess is changed. This effect is greater if the subject himself chooses the value of the guess, thus suggesting some form of "involvement" or what Squires et al. (1973a) called "committment" to the decision. In Sutton's case however, value would appear to be closely linked to the confidence with which a decision was made (Hillyard et al., 1971) rather than being a separate, isolated factor.

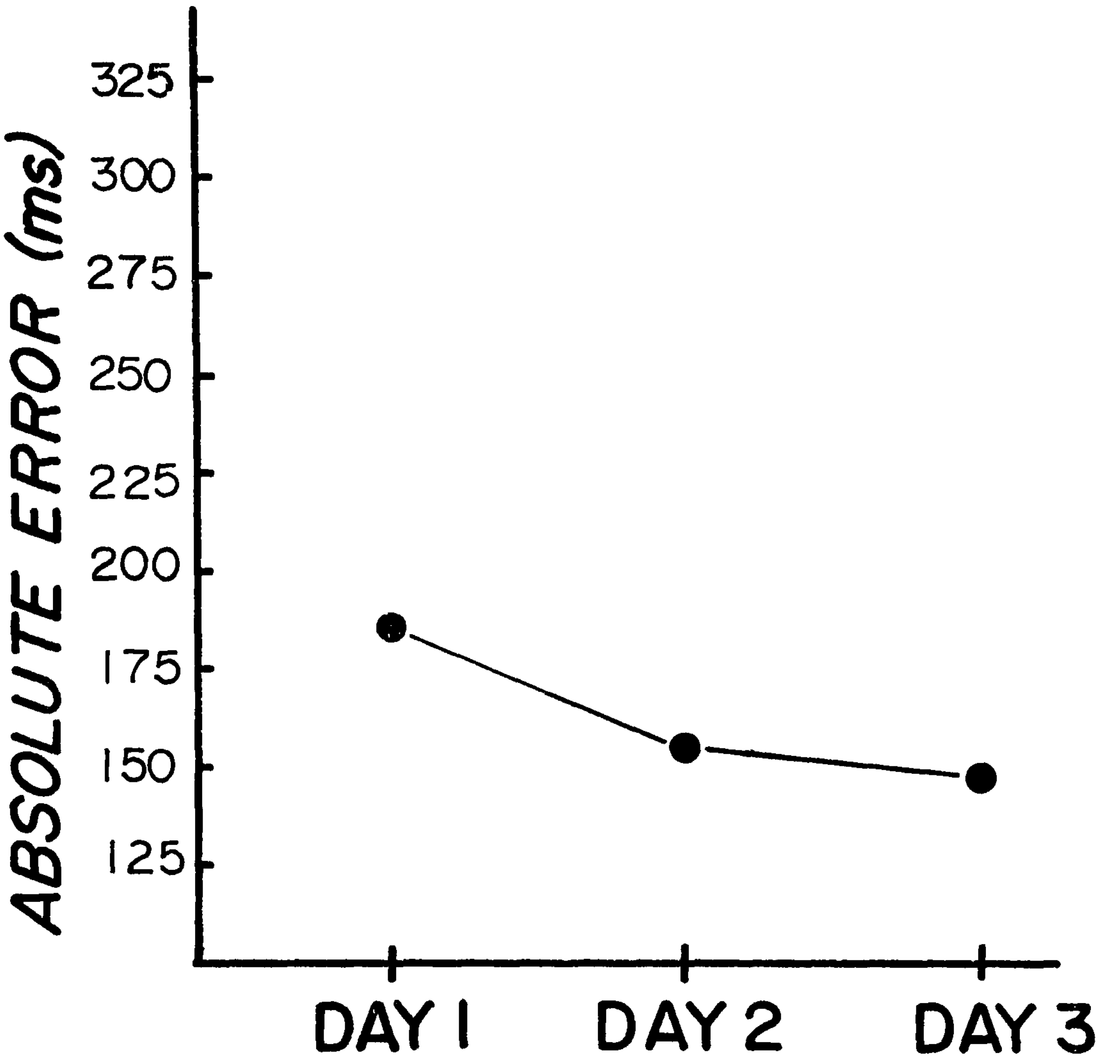
Across Day Comparisons

Both behavioural and physiological changes were apparent between Days 1, 2 and 3. In order to establish significance of these apparent changes, one condition from each day was selected for further analysis. The narrow window condition on Day 1 and the QUAN condition on Day 3 contained feedback signals that had the same amount of task relevant information. On Day 2, the no incentive condition, besides being comparable with these two other conditions due to the fact that no monetary payoff was provided, was also closely akin in terms of information contained in the confirming, disconfirming-under, and disconfirming-over feedback signals.

The mean absolute error for each day is plotted in Figure 20 . The analysis of variance failed to indicate significant improvement across the days, F (2,14) = 1.70 conventional $p > .01$, conservative $p > .10$, this in spite of a 30 ms decline in error from Day 1 (narrow window) to Day 2 (no incentive). The Day 1-Day 2 improvement in performance then offers a hint at a type of learning which some open-loop theorists, postulating "momentary states," deemed not to be likely (Briggs et al., 1957). Moreover the maintenance of improved performance from Day 2 to Day 3 advances evidence that the learning effect is permanent and not momentary. The decrease in error from Day 2 to Day 3 being less than 10 ms suggests that there is a limit or ceiling to the extent to which improvement in performance is possible.

A much more convincing argument for learning effects was shown by a comparison of control conditions. A fundamental claim of closed-loop theorists is that a reference mechanism of some sort is established on the basis of which decisions can be compared (Adams, 1968; Sokolov, 1963). On Day 1, a control condition was run in which relevant feedback was not available to the subject, making error detection impossible. Similarly on Day 3, two more control conditions were run, while none was run on Day 2. Since feedback was not provided, the only means available to the subject for maintaining accuracy was via the hypothesized reference mechanism. The establishment of such a mechanism is however gradual, occurring only after a large number of trials (Adams and Bray, 1970). The effects of absence of feedback would thus be expected to be most

Figure 20. Mean absolute time estimation error associated with task relevant feedback on Days 1, 2, and 3.


ABSOLUTE ERROR (ms)
325
300
275
250
225
200
175
150
125
DAY 1
DAY 2
DAY 3

dramatic on Day 1, when a reference mechanism was, at this point in time, not firmly developed. Figure 21 plots the mean absolute error on both days. The analysis of variance strongly ratified these expectations, F (2,14) = 6.51, conventional p <.01, conservative p <.05, post-hoc testing showing a significant decline in error between the control condition of Day 1 and those of Day 3. Table 28 presents the analysis of variance for the control data.

The physiological data as well pointed to a changed waveform over the days. At the Cz location, the prior CNV grew progressively larger in amplitude over the time period, F (2,14) = 5.81, conventional p <.01, conservative p <.05, the difference in amplitude however only being significant between Days 1 and 3 (Table 29). This same finding was replicated both at Fz, F (2,14) = 6.71, conventional p <.01, conservative p <.05 and at Pz, F (2,14) = 8.35, conventional p <.01, conservative p <.05, indicating that the effect was widespread. Low and Swift (1971) noted that subjects with prior laboratory experience tended to produce greater amplitude CNV than naive subjects, due to a greater familiarization with experimentation and thus decreased anxiety (Knott and Peter, 1974) associated with it. Following this line of reasoning, it is likely that subjects on the second and third days of testing approached the sessions in a much more relaxed manner after having become well-acquainted with the procedure and laboratory situation. Indeed subjective reports of many subjects following Experiment 1-1 pointed to a great deal of tension associated with the methodological procedures:control of blinking,

Figure 21. Mean absolute time estimation error associated with control conditions on Days 1 and 3.

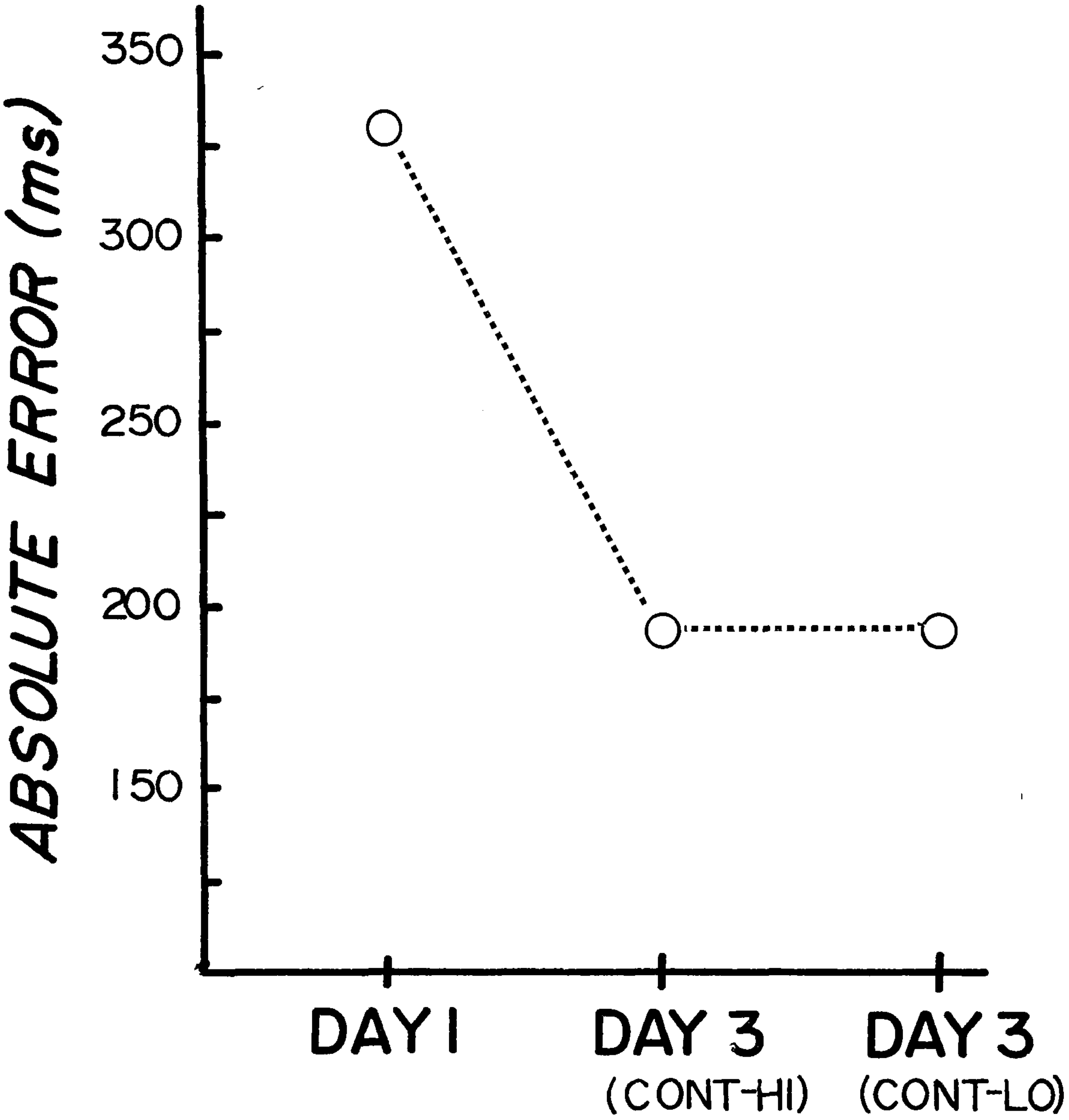

ABSOLUTE ERROR (ms)
350
300
250
200
150
DAY 1
DAY 3
(CONT-HI)
DAY 3
(CONT-LO)

Table 28

Analysis of Variance of Behavioural Data
for Control Conditions on Days 1 and 3

Source of Variation	SS	df	MS	F
Between Subjects				
R (Replication)	105866.4	7	15123.8	
Within Subjects				
A (Treatment)	102954.5	2	51477.2	6.52 * @
A x R	110577.6	14	7898.4	

Conventional $\underline{F}_{.99}$ (2,14) = 6.51

Conservative $\underline{F}_{.95}$ (1, 7) = 5.59

* conventional $\underline{p} < .01$

@ conventional $\underline{p} < .05$

Table 29

Analysis of Variance of Pre-Feedback CNV (Cz Location) for Correct, Under, and Overestimation Feedback Signals on Days 1, 2, and 3

Source of Variation	SS	df	MS	F
A (Day)	321.25	2	160.62	5.80 * @
A x R (Replication)	387.53	14	27.68	
B (Feedback)	20.94	2	10.47	1.04
B x R	140.81	14	10.06	
A x B	114.41	4	28.60	2.78
A x B x R	288.08	28	10.29	
R	944.84	7	134.98	

Conventional $\underline{F}_{.99}$ (2, 14) = 6.51

Conservative $\underline{F}_{.95}$ (1, 7) = 5.59

* conventional $\underline{p} < .02$

@ conservative $\underline{p} < .05$

fixation of eyes, as well as the time estimation task. Neither component N1, P2, nor N2 showed any similar growth over the three days of experimentation. On the other hand, P3 increased in magnitude by about 10% daily, the increase however just failing to reach significance at Cz, $\underline{F}$ (2,14) = 2.89, conventional $\underline{p} < .10$, conservative $\underline{p} < .25$, or at Fz, $\underline{F}$ (2,14) = 3.69, conventional $\underline{p} < .05$, conservative $\underline{p} < .10$, or at Pz, F (2,14) = 3.90, conventional $\underline{p} < .05$, conservative $\underline{p} < .10$. A tendency towards CNV-P3 covariation was thus seen across the three days. Aside from this exception, however, no other consistent relationship was found. The changes in prior CNV and P3 as a function of the day of experimentation are shown in Figure 22 .

Components later than P3 (i.e., N3, P4 and post-feedback resolution) did not show any significant daily fluctuation, nor did any of the peak-to-peak measures, N1-P2, N1-P3, or N1-P4. Sample records of one subject, MP, are traced in Figure 23 illustrating daily waveform changes.

Across Scalp Comparisons

In order to obtain a preliminary understanding of the role of cortical region with respect to the processing of confirming and disconfirming feedback, the middle window of Experiment 1-1 and the no incentive condition of Experiment 2-1 underwent further analyses, examining components P2, P3, and P4. The amplitude of each component at Fz was subtracted from that of Pz and then divided by Pz (Pz - Fz/Pz) providing an index of cortical dominance. Both P2 and P3 were reduced approximately 20% frontally in both experiments while P4 was down by about 40%. Disconfirming

Figure 22. Changes in pre-feedback CNV and P3 mean amplitude (Cz Location) across the three days of experimentation.

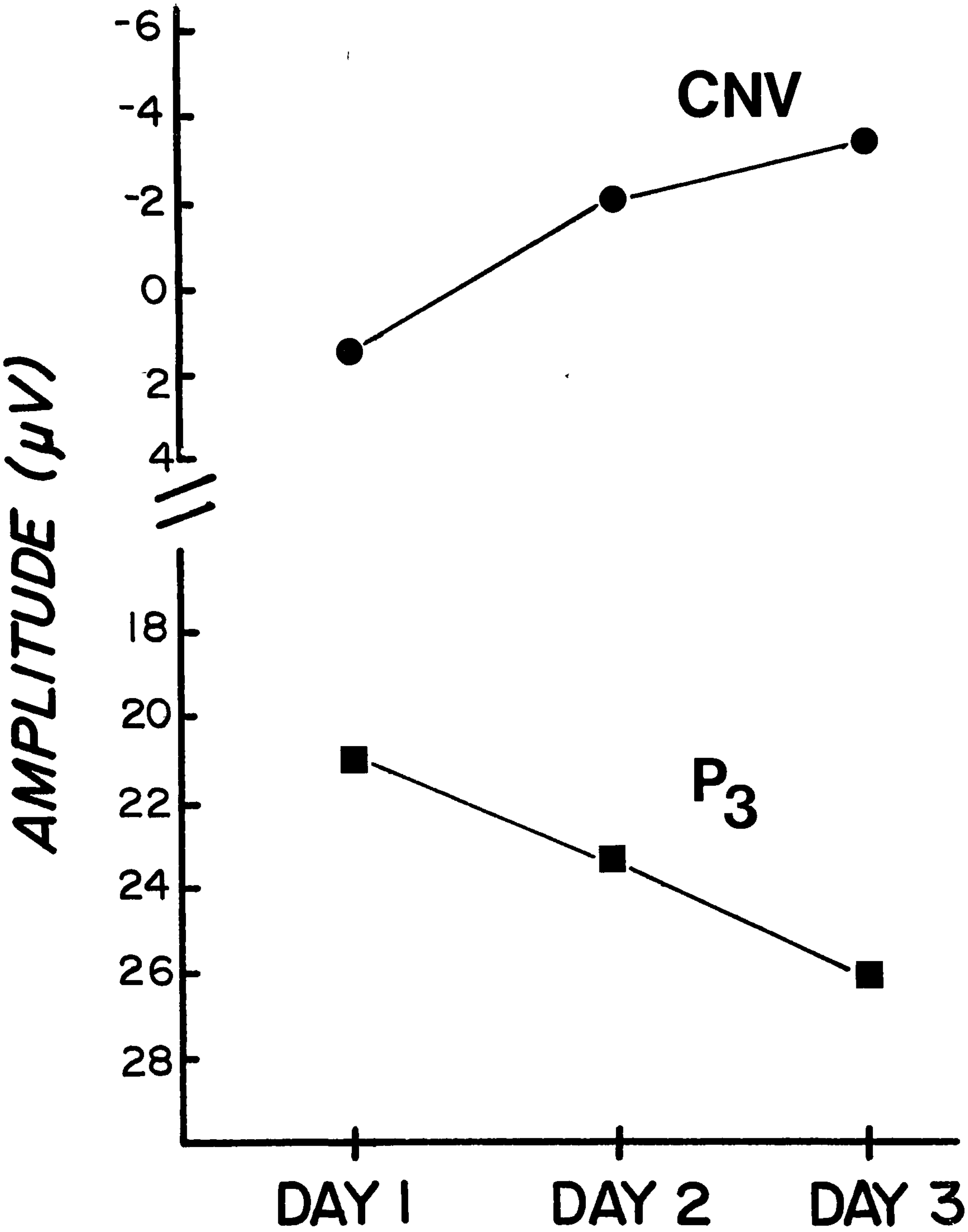
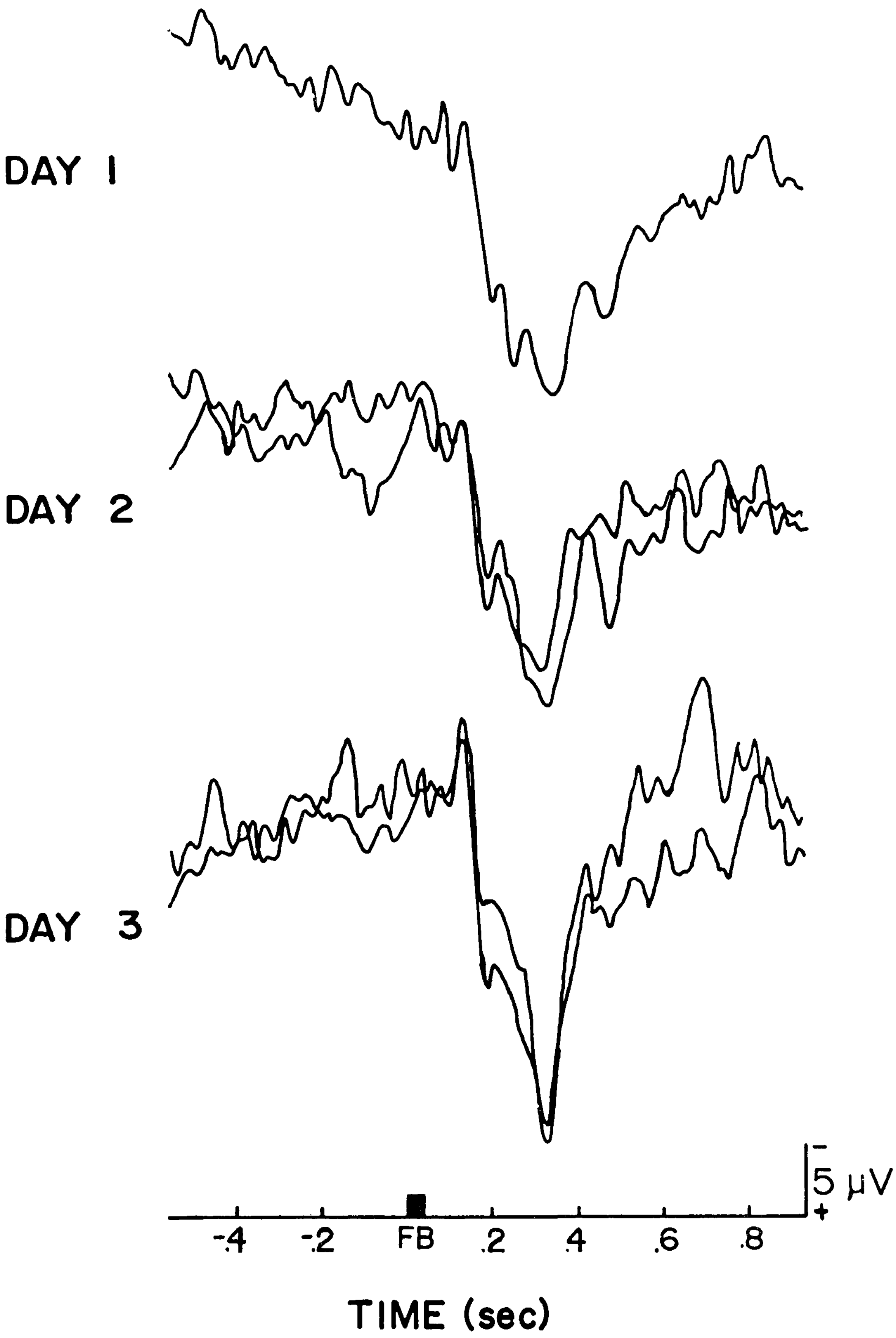

CNV
P3
AMPLITUDE (μV)
-6
-4
-2
0
2
4
18
20
22
24
26
28
DAY 1
DAY 2
DAY 3

Figure 23. Average evoked potential changes in pre-feedback CNV and P3 across days for one subject, MP. Note especially the increased negativity for the pre-feedback CNV, and increased positivity for P3 across days. Double tracings are replications of the same conditions. Responses are those to correct feedback signals.



ACROSS DAY COMPARISONS S:mp

feedback however tended to have a greater frontal effect than confirming but only for the P3 component. Neither P2 nor P4 revealed any consistent frontal/parietal confirming/disconfirming influence. Because of the P3 disconfirming-frontal location interaction, further analysis was carried out with this component employing a expanded range of conditions. The narrow, middle, and wide window conditions from Experiment 1-1, as well as the negative, positive, negative and positive, and no incentive conditions from Experiment 2-1, and the QUAN condition from Experiment 3-1 were selected. Over these eight conditions P3 was largest parietally being reduced 30% frontally when evoked by confirming feedback, but reduced only 17% by disconfirming-under feedback and 22% by disconfirming-over feedback. The analysis of variance for P3 suggested disconfirmation evoked significantly greater frontal activity than confirmation, $\underline{F}$ (2,14) = 5.00, conventional $\underline{p} < .02$, conservative $\underline{p} < .10$. When the N1-P3 peak-to-peak measurement was taken into consideration, the frontal enhancement for disconfirmation was far more definite, $\underline{F}$ (2,14) = 8.43, conventional $\underline{p} < .01$, conservative $\underline{p} < .05$, post-hoc testing showing that for both under and overestimation, P3 was significantly more frontal than correct estimations. Table 30 presents a summary of the N1-P3 analysis of variance, while Figure 24 plots the means at Fz, Cz, and Pz of the eight conditions for the three types of feedback. Figure 25 provides samples (subject JBB) of the waveform at the three scalp locations for the narrow, middle, and wide window conditions of Experiment 1-1.

Figure 24. N1-P3 mean amplitude at frontal, central, and parietal locations as a function of decision outcome. The mean represents an average of eight conditions selected from Days 1, 2, and 3.

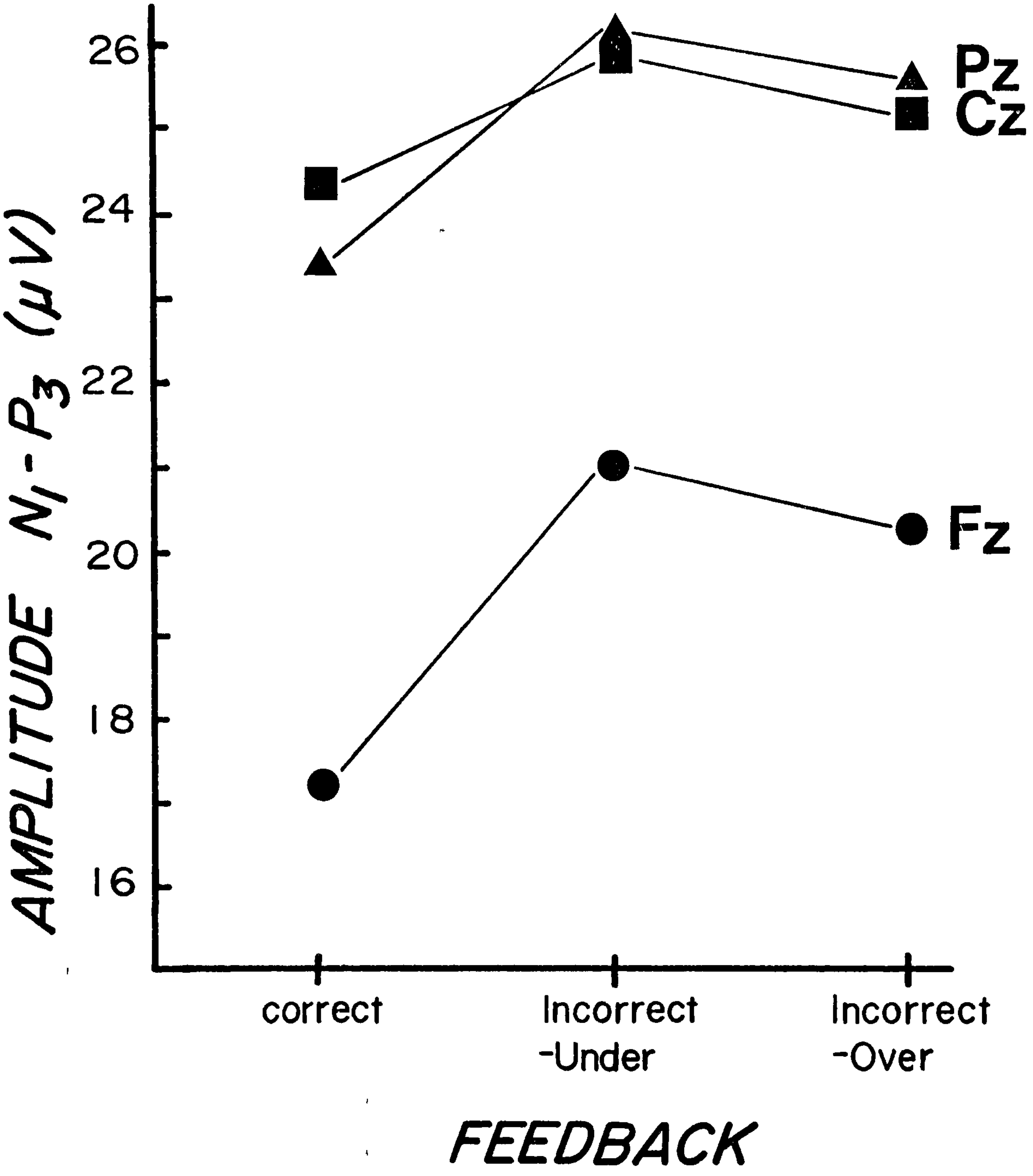

AMPLITUDE N1-P3 (μV)
26
24
22
20
18
16
Pz
Cz
Fz
correct
Incorrect -Under
Incorrect -Over
FEEDBACK

Figure 25. Average evoked potentials for one subject, JBB, at frontal, central, and parietal locations as a function of decision outcome. Note especially the change in the evoked potential configuration for disconfirmation, particularly with the narrow window, a period in which error were very frequent. Double tracings are replications of the same condition. Solid lines represent responses to correct estimations, dotted, those to underestimations, and broked lines, those to overestimations.

SCALP DISTRIBUTION - DAY I S: jbb

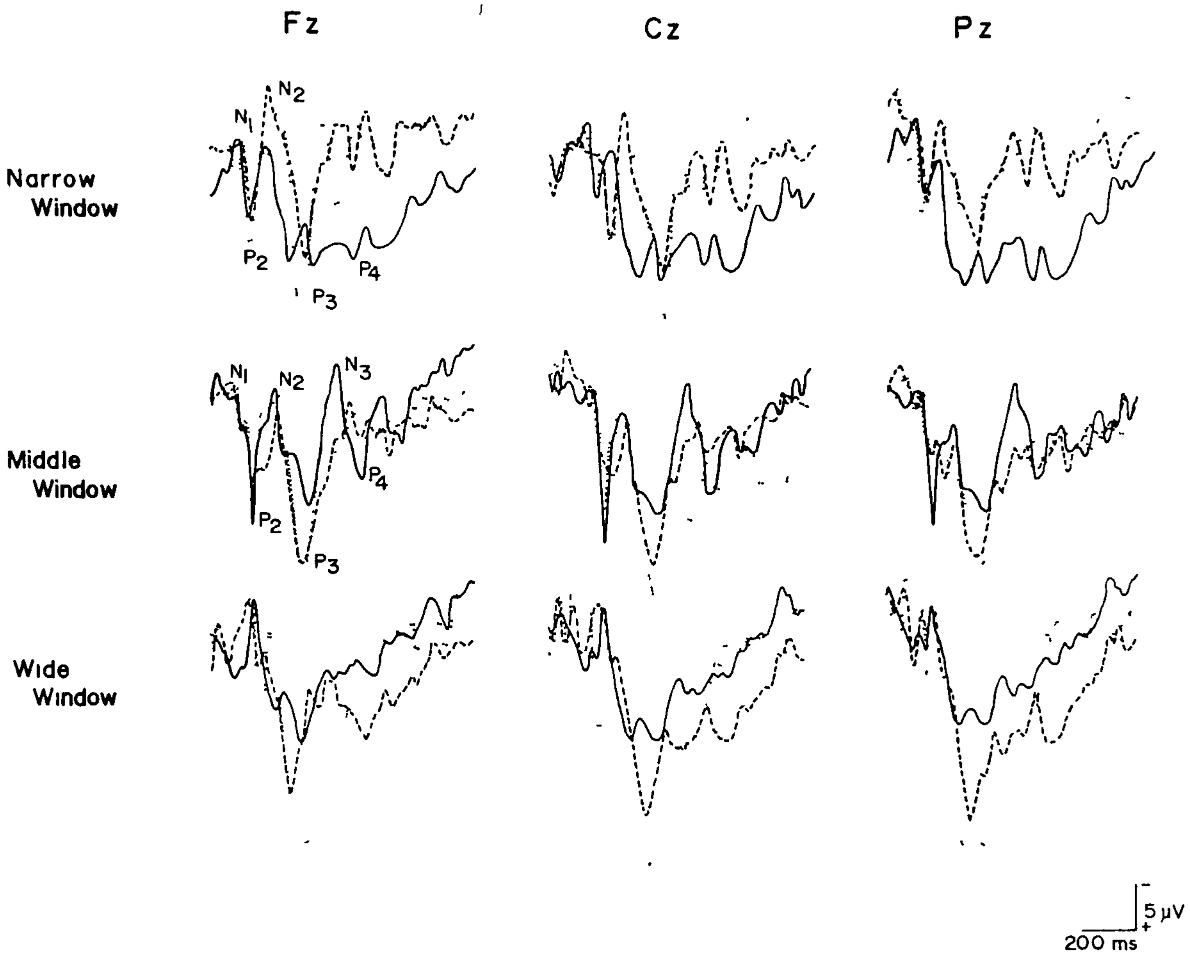


Table 30

Analysis of Variance for N1-P3 Peak-to-Peak Measure --Pz/Fz Ratio--for Correct, Under, and Overestimation Feedback Signals under Eight Treatment Conditions

Source of Variation	SS	df	MS	F
A (Treatment)	31.89[a]	7	4.56[a]	1.65
A x R (Replication)	135.67	49	2.77	
B (Feedback)	45.75	2	22.87	8.43 * @
B x R	37.96	14	2.71	
A x B	33.24	14	2.37	1.02
A x B X R	226.94	98	2.32	
R	265.03	7	37.86	

a. To facilitate comprehension, the sum of squares and mean square have been multiplied by a constant, 100.

Conventional $\underline{F}_{.99}(2,14) = 6.51$ * conventional $\underline{p} < .01$

Conservative $\underline{F}_{.95}(1, 7) = 5.59$ @ conservative $\underline{p} < .05$

Correlational Analyses

To ascertain the degree of common variance shared by the various components of the evoked potential, the raw data from the vertex (Cz) location for all conditions on the three days was correlated, the resulting matrix appearing as Table 31 .

The very low correlation between P3 and prior CNV strongly reinforces the data of those authors who claim independence between the two (Donchin et al., 1973; Tueting and Sutton, 1973). Secondly some degree of common variance was shared between components P2 and P3 (36%), and similarly between P3 and P4 (43%). A similar finding has also been reported by Wilkinson and Ashby (1974) who called the P2-P3-P4 peaks, a "wave of positivity". Independence between the peaks was however earlier revealed based on differential experimental effects (P2 and P3) and different cortical relatedness (P4 much more parietal than P3).

Individual day-to-day correlational matrices essentially replicated these overall findings. In addition,on Day 2 the various components were also correlated with the monetary value attached to a particular stimulus. The largest correlation found was with component N3, $\underline{r} = .15$, suggesting that as monetary value increased, N3 became more positive. The positive pull however was not due to either P3 or P4 influences. P3 showed almost no relationship to value, $\underline{r} = -.07$, while with P4, $\underline{r} = .07$. The correlational data then further substantiate the earlier ANOVA results. Payoff has little influence in the determination of P3.

Table 31

Correlational Matrix for each of the Components
of the Evoked Potential Amplitude Measures over
the Entire Three Days of Experimentation

	N1	P2	N2	P3	N3	P4	Post FB
Prior CNV	.03	.19	.11	-.06	-.30	-.32	-.53
N1	-	.56	.60	.41	.22	.19	.06
P2		-	.82	.57	.13	.34	.06
N2			-	.70	.28	.39	.17
P3				-	.43	.66	.39
N3					-	.61	.52
P4						-	.67

The positive components, P2, P3 and P4 were then correlated with surprisal, task relevant information contained in the stimulus, average uncertainty reduction (average surprisal) and average amount of task relevant information. The latter two measures served as a crude measure of expectation to receive a particular type of feedback for the subject. Three sets of matrices were calculated. The first took the "objective" probability of occurrence of a particular signal (probability of which subject was informed prior to commencement of a particular condition) and was therefore correlated to the mean amplitude response of the eight subjects for a particular stimulus within a particular condition. On Day 2, in Experiment 2-1, all feedback stimuli contained exactly the same amounts of task relevant information and were equally surprising. Thus the grand mean for each component was calculated and compared to the informational properties for the three signals.

A second correlation matrix was calculated by employing raw amplitude scores across the three days and comparing them to the respective "subjective" informational properties of the various stimuli. Although subjects were informed of the confirming/disconfirming ratio prior to the start of each condition, it often happened that an individual's particular performance would cause a deviation from this prior expectation. Hence for each condition for each subject, the degree of task relevant information in a stimulus, its amount of surprisal as well as the average uncertainty reduction and amount of task relevant information was calculated and correlated with the amplitude of the positive components evoked by the stimulus at hand.

A third correlation took into account the accepted notion of individual differences associated with evoked potential waveforms. Under identical situations, the amplitude of the evoked potential for any two subjects might significantly vary. A "normalization" technique then was utilized to reduce inter-subject variability, the amplitude of the various components under the various conditions for each subject being divided by the respective subject's overall grand mean amplitude over the three days and then correlated with "subjective" informational properties for each stimulus.

Table 32 and Figure 26 present the correlational data for the three techniques. When mean scores were compared to "objective" measures of information, a correlation of .89 was found between P3 mean amplitude evoked by a particular stimulus and that stimulus' degree of task relevant information. With surprisal the correlation was low at .31 and was also not significant for average uncertainty reduction. When the average amount of task relevant information was utilized in the analysis, another very high correlation of .89 was found. P2 and P4 were also rather highly correlated with the degree of task relevant information again demonstrating a shared variance with component P4.

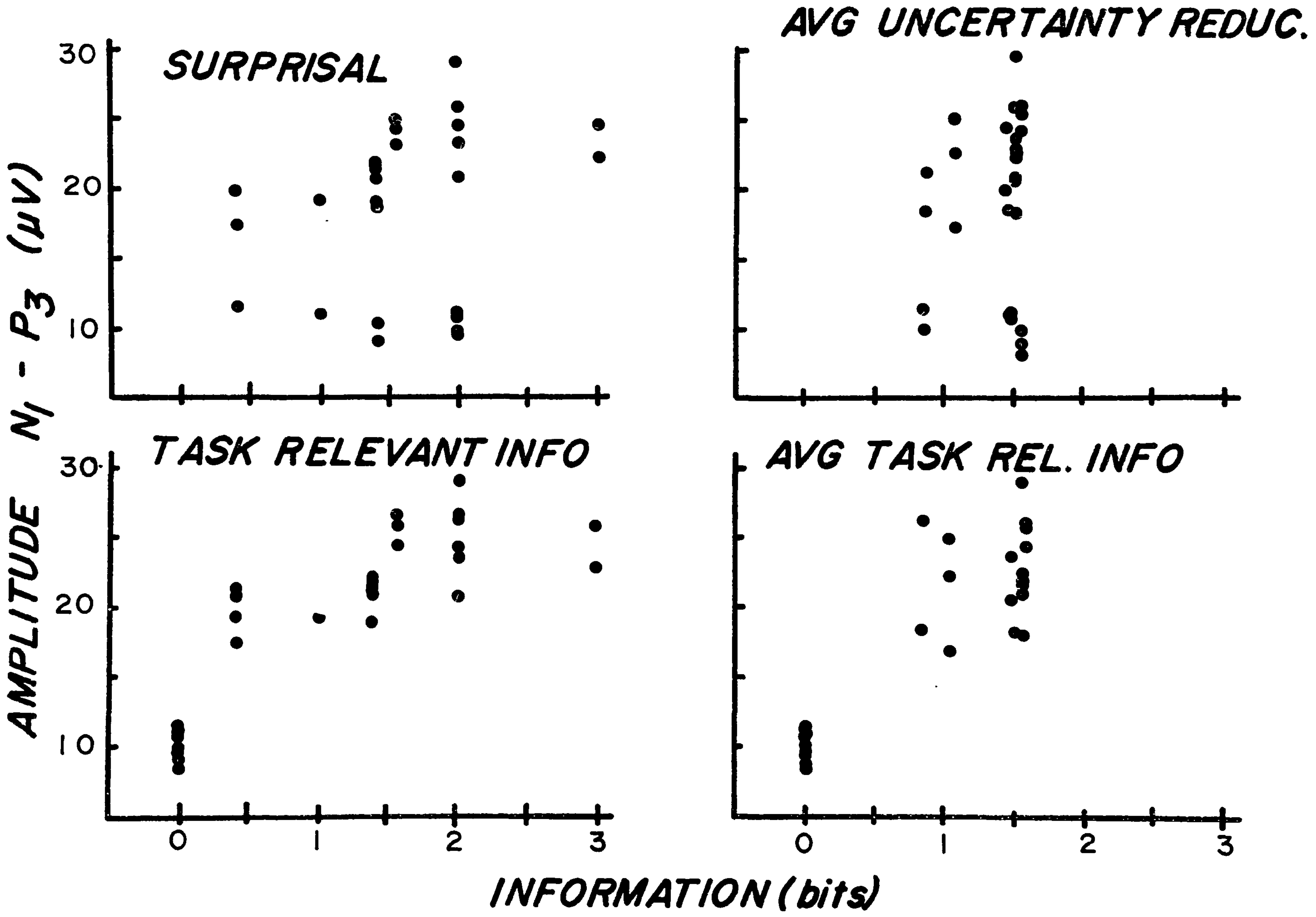
When raw data or "normalized" raw data were correlated with actual measures of informational content, correlations,although lower,were in the same direction. However, while the correlation between P3 and task relevant information hovered around the .50 mark, that with P2 dropped sharply to .26 and for P4, .43. In this context then, P2 and P3 appeared to be affected by this factor to different degrees.

Table 32

Correlation Matrix of Various Amplitude Measures of the Evoked Potential and Measures of Information Contained in the Signals

COMPONENT 1. Mean data 2. Raw data 3. Normal. raw data	SURPRISAL	TASK RELEV. INFORMATION	AVG UNCER. REDUCTION	AVG TASK REL INFO
P2	.36	.86	.16	.80
	.05	.23	.04	.29
	.05	.26	.07	.35
N1-P2	.29	.81	.20	.84
	.10	.24	.02	.27
	.09	.27	.04	.31
P3	.30	.89	.21	.90
	.22	.44	.10	.47
	.23	.50	.14	.56
N1-P3	.27	.85	.24	.92
	.26	.46	.10	.47
	.23	.50	.12	.53
P4	.23	.77	.28	.92
	-.01	.04	.05	.11
	.19	.43	.17	.55
N1-P4	.10	.61	.32	.90
	.18	.41	.18	.53
	.25	.41	.13	.46

Figure 26. Scattergram of informational properties of the stimulus and subsequent N1-P3 amplitude.


SURPRISAL
AVG UNCERTAINTY REDUC.
TASK RELEVANT INFO
AVG TASK REL. INFO
AMPLITUDE N_1 - P_3 (μV)
30
20
10
30
20
10
0
1
2
3
0
1
2
3
INFORMATION (bits)

Nevertheless based on both the analyses of variance and the correlational analyses, it would seem that the magnitude of P3 is largely dependent on the degree of task relevant information contained in the stimulus. However, some other considerations are also important such as underlying cortical regional differences. Disconfirmation for example appears to have a more dramatic effect frontally than confirmation.

Inter-subject Variability

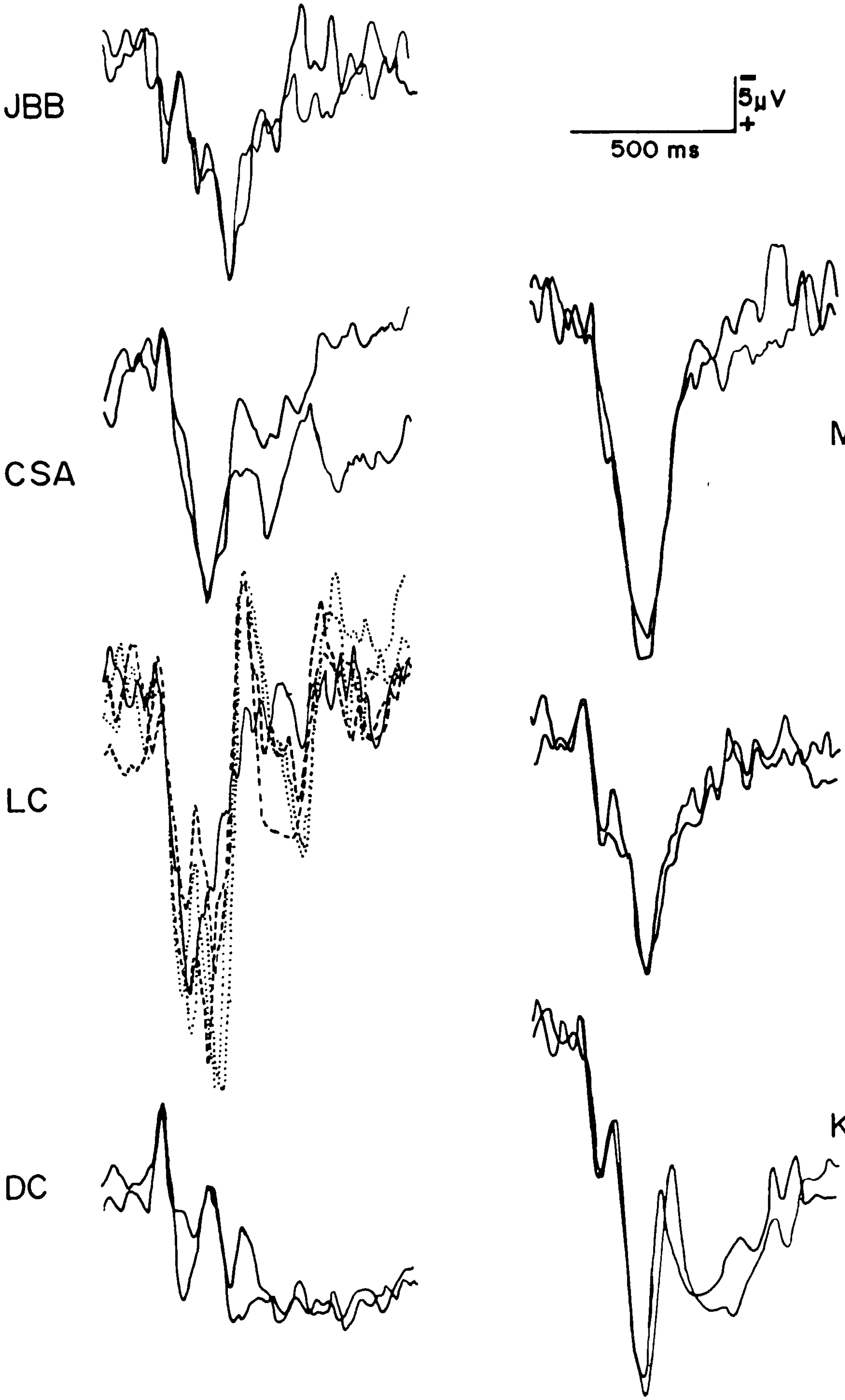
While most subjects showed consistently replicable waveform patterns across the various conditions and days, except for occasional changes as previously noted, there was some degree of variation between subjects this particularly being the case with the later components, N3 and P4. Figure 27 illustrates particular idiosyncracies. Subject JBB often showed an early double negative peak. Her initial N1 peak was within the latency range of most subjects, but her P2 and N2 components were of much shorter latency. The N2 in fact appears to be very similar to Simson et al.'s N190 which they felt was part of an early decision complex. In some instances distinctive P2 and N2 peaks were missing (subjects CSA and MH,giving the impression of a combined P2-P3 peak (Squires et al., 1972a). Even with these two subjects, however, this was much more often the exception than the rule.

Components N3 and P4 manifested the greatest amount of variability perhaps due to problems with time-locking considering the lateness of onset (450-550 ms). One subject, LC, often displayed very sharp, N3-P4 peaks. On Day 3, N3-P4 was particularly sharp but only for errors. On the other hand,subject MP sometimes failed to exhibit distinctive P4 peaks, while subject DC at times showed a combined P3-P4 "falloff" wave. Subject KA on occasion mimicked the slow wave (SW) of Squires, N., et al. (1975),rather than displaying sharp peaks as was the case with LC.

Whether these individual differences are due to confounding problems associated with the averaging process or reflect individual patterns related to cognitive activity cannot as yet be determined. Certainly it would be most unlikely that subjects adopted a uniform decision-making schemata.

Figure 27. Inter-subject average evoked potential variability. Subject JBB shows an early double negative peak, subjects CSA and MH, a combined P2, P3 peak, N2 being very small or absent. Subject LC displayed a sharp N3-P4 peak but only to disconfirming feedback signals, while subject MP hardly manifested any P4 peak. Subject KA's P4 took on a slow wave configuration, and subject DC's P4 was a combined P2-P3-P4 wave. Double tracings are replications.

In the case of subject LC, the solid lines are the average evoked potentials to correct feedback, while the dotted lines are those to incorrect-under feedback, and the dashed lines, those to incorrect-over.


JBB
CSA
LC
DC
MH
MP
KA
–
5µV
+
500 ms

CHAPTER IV

Discussion

During the presentation of the results, individual aspects of the behavioural and physiological data were briefly interpreted. This chapter will expand on these interpretations,integrating the findings over the three days.

Behavioural Outcome

Both Day 1 and Day 3 results indicated that error associated with time estimation significantly decreased when task relevant feedback signals were utilized to inform the subject of the outcome of her judgement. This was the case with respect to both qualitative (correct, incorrect) and quantitative (correct, incorrect-under, incorrect-over) feedback signals, affirming a large number of previous reports (Baker and Young, 1960; Bilodeau et al., 1959; Harton, 1939; Hornstein, 1969; Roeckelin, 1972; Rogers, 1974). It appears almost certain that the information concerning past events (knowledge of results or feedback) serves to provide a basis for improved performance on future trials.

Over the three days of experimentation there was improvement in task performance with a notable but nonsignificant decline in error from Day 1 to Day 2, carrying over to Day 3. This represents a type of learning. Briggs et al. (1957) proposed that feedback was a momentary determiner of behaviour with no persistence from past trials. The fact that subjects did display some improvement in the task with experience suggests that there was persistence across days.

Closed-loop theorists (Adams, 1968; Chase, 1965a, 1965b) interpret learning as a gradual imprinting of a "neural model" or "perceptual trace", in short, a reference mechanism, against which past trial performance is compared and modulated. Increased precision on Day 2 provides partial evidence for the establishment of a perceptual trace of the 1000 ms interval. This might have been due to increased incentive or motivation. More important is the fact that the improved performance seen in Day 2 continued into Day 3 suggesting some sort of permanent rather than temporary effect. Stronger foundation for the gradual establishment of a time reference comes from a comparison of Day 1 and Day 3 control conditions. On Day 1, without the aid of task relevant feedback significant deterioration resulted. According to Adams (1968), as the trace becomes stronger after a large number of trials, the correct response can be maintained in the absence of feedback. The Day 1 - Day 3 drop in error with control conditions supports this claim.

Physiological Results

It is clear that some form of feedback was essential to the improvement of accuracy of performance on the time estimation task. Physiologically two intervals were studied, a prefeedback (prior CNV) and a post-feedback (evoked potential period).

Prior CNV There were no significant changes in prefeedback activity related to experimental manipulations except for an increase in CNV on each day of the study. Although not significant, CNV tended to be largest in irrelevant feedback conditions and when stringency for success was eased (wide window of Experiment 1-1). With task relevant feedback, CNV tended to be depressed. Delse et al. (1972) have found that smaller CNVs were associated with the more difficult discriminations in a tone discrimination task. Similarly Poon et al. (1976) found that as the complexity of the task increases, CNV decreases while Roth, Kopell, Tinklenberg, Parley, Sikora, and Vesecky (1975) reported a smaller CNV during a short-term memory problem. However, in most of these studies the pre-response CNV was measured. There have been no pre-feedback CNV studies other than Friedman et al. (1973), Picton and Low, (1971) and Weinberg (1974).

The depression of negative-going activity for task relevant feedback conditions might be a demonstration that during these more cognitively demanding tasks, the DC "baseline" activity is close to its maximum negativity. Knott and Irwin (1967) first used such an explanation to interpret low CNV in highly anxious and aroused subjects. Knott and Peters (1974) showed that the depression of CNV during "arousing" tasks was particularly apparent for female subjects, which might also help to account for the present findings.

In postexperimental interviews many subjects reported that they were under much more stress and tension during task relevant conditions. Concentration on and alertness to feedback and stimulus cues was particularly high.

An hypothesis following the same line of reasoning might explain the linear increase seen in CNV from Day 1 to Day 3. As subjects adapted to the laboratory situation and electronic "gadgetry" and grew familiar with the demands of the task, a decrease in anxiety and tension likely resulted, with a concomitant increase in CNV amplitude. Low and Swift (1971) reported that prior subject familiarity with experimental laboratories had significant effects on CNV. Experienced subjects showed much larger CNV activity than naive subjects, the explanation being that the former approached their second or subsequent experiment with considerably less anxiety than the first. Indeed in Experiment 1-1, the one subject who had participated in previous evoked potential research manifested one of the largest CNVs on Day 1. McAdam et al. (1966) likewise proposed that the subject's set within any given study is significantly affected by experience.

An alternate explanation might derive from the learning aspects of this study. As subjects learned the solution to the task with the likelihood of development of a perceptual trace, prefeedback CNV mirrored this process. Poon et al. (1974) have however shown that as a solution is gradually acquired, CNV decreases rather than increases.

Scalp topography comparisons indicated that prior CNV is largest in central-parietal regions. This might reflect a priming of visual association areas for the reception of the feedback stimulus or it might also reflect some activity of areas in the parietal region linked with time information. The posterior dominance of the records is in accord with those of Cohen (1969), Naatanen and Gaillard (1974), Poon et al. (1974, 1976), and Weinberg and Papakostopoulos (1975). Previous reports of frontal CNVs (Jarvilehto and Fruhstorfer, 1970; Walter, 1964) in non-feedback paradigms suggest that it (CNV) is not a unitary brain phenomenon but rather dependent on a host of task relevant demands.

A further interpretation of the posterior effects is that the CNV reflected a priming or preparation for not so much for a visual input but for a particular type of information processing. There seems to be reasonably strong evidence that stimuli, at least complex ones, are first processed in a parallel or simultaneous manner (Averbach and Sperling, 1961; Neisser, 1967; Sperling, 1960). Simultaneous processing refers to the synthesis or integration of separate elements into groups, any portion of the results being at once surveyable without dependence upon its position in the whole (Das et al., 1975; Luria, 1966a, 1966b; Pribram, 1969). Both clinical and experimental research center this type of processing in the parietal-occipital area, the CNV perhaps indexing such activity.

N1-P2 Post-feedback changes were influenced by a number of the independent variables. The baseline - N1 peak was quite small in amplitude, perhaps due to the low intensity of the LEDs or to overall suppression of negative activity as was seen in the case of the CNV. Simson et al. (1976) also reported small N1 components to tachistoscopically presented visual stimuli.

Although N1 only rarely showed significant relationships with any of the independent variables, some consistent effects were noted. Disconfirming feedback, independent of its probability of occurrence, on each of the three days of experimentation, evoked N1 components 1.5 to 2 μV larger than confirming feedback. Surprisal then cannot account for the N1 results -- with the narrow window of Day 1 and throughout Day 3, disconfirming feedback were objectively less surprising than confirming yet still evoked larger magnitude N1s. A possible reconciliation of the data comes from the behavioural interpretation of Adams (1970). In spite of the objective likelihood to the contrary, Adams claims that most subjects adopt a uniform low expectancy of being incorrect. In this sense disconfirmation, regardless of its objective frequency, is subjectively a surprising event. The disconfirmation-confirmation difference was significant only at the Fz location on Day 1, perhaps indicating a type of frontal orienting response (Courchesne et al., 1975; Ford et al., 1976; Squires, N. et al., 1975). Caution must however be held with regard to the orientation aspect of N1. While disconfirming stimuli might have been surprising to the subject, they cannot be regarded as being truly novel in the Sokolovian sense.

Yet another possible explanation for the N1 increase with the disconfirming (surprising) event is that the origin of the positive process underlying P2, P3, and P4 might begin earlier for the confirming (expected) stimulus. N1 then might be the negative component that has been related to the decision process (Simson et al., 1976), invariably called N2, N190, or Nx (Tueting, 1976). A number of reasons dictate against such an interpretation. The latency for confirming and disconfirming feedback did not differ. Moreover the mean latency of 155 ms is earlier than

Simson et al's. 190 ms. In the vast majority of cases a clear P2 component was present, N1 thus not being an overlay with N2,and finally it (N1) was present in control conditions where decision processing is markedly reduced.

The P2 analysis showed strong, consistent and significant feedback effects. When feedback stimuli were task irrelevant, the amplitude of P2 was significantly attenuated. Jenness (1972a) and Sutton et al. (1965) also detected a reduction in P2 amplitude in conditions in which stimuli were not "salient". A wide variety of experiments have reported variation in the size of N1-P2 with variation in the relevancy of the stimulus (Chapman, 1965; Chapman and Bragdon, 1964; Davis, 1964; Donchin and Cohen, 1967; Koppell, Wittner, and Warrick, 1969; Wilkinson and Lee, 1972). Criticism of these studies has been raised on the grounds that N1-P2 showed enhancement only in predictable settings (Naatanen, 1967, 1975; Wilkinson and Ashby, 1974). Augmentation of N1-P2 was caused by non-selectively increased readiness of the organism before relevant stimuli, increased reactiveness being indicated by the CNV. In the present study, the occurrence of relevant stimuli was certainly predictable. In reply to these criticisms, several recent studies have shown independence of CNV and the ensuing P2 and especially P3 components (Donchin et al., 1975; Eason et al., 1969; Hillyard et al., 1973).
If CNV and P2 co-vary, why did P2 manifest experimental manipulation while CNV did not? Moreover the correlation between CNV and P2 was very low and in the wrong direction. As CNV became more negative, there was

a slight tendency for P2 to become smaller,not larger,as Naatanen has proposed. Karlin (1970) and Wilkinson and Ashby (1974) have presented a second non-cognitive hypothesis, based on the positive resolution of prior CNV negativity. The resolution of CNV will be discussed in the section on P3.

P2,while differentiating between relevant and irrelevant feedback, did not further differentiate between amount of task relevant feedback information, surprisal, incentive, or value. A fairly large amount of the variance in P2 could be explained by the variance in task relevant information content. Even though this may be related to situations in which feedback was irrelevant, the possibility of P2-P3 covariance remains.

P2 appears to be the first stage of processing of task relevant information indexing whether the signal provides feedback cues or not. Taken in this light it seems analagous to Broadbent's (1971) stimulus set or Das et al's. (1975) sensory register. A stimulus set preferentially admits all relevant sensory input for further perceptual analysis, while blocking or attenuating irrelevant inputs.

Topographically, P2, like the later positive component, P3, is widespread being maximum in parietal regions. Simson et al. (1976) in their multichannel recording study,noted that P2 was very largely a parietal-occipital phenomenon. Their task, however, differed from the present one in that their concern was primarily one of the response to a present or absent visual stimulus. The feedback signals in the present study might be considered to be "higher order" stimuli. The posterior aspects of P2 are indicative of the primary and secondary aspects of visual processing. The frontal aspects of P2 may be a reflection of the beginnings of the planning, programming, and regulation processing associated with feedback related frontal lobe functioning.

The LPC, P3 A later positive peak, P3, was observed to widely vary with the various experimental manipulations. N1-P3, because of its consistency, was chosen as a more appropriate measure in some experiments rather than the baseline - P3 difference because of baseline N1 biases.

Regardless of the measure, task relevant feedback evoked unusually large P3 components, paralleling the P2 results. Several hypotheses have been put forward in an attempt to interpret P3 relationships. Those that were deemed relative to the feedback results will thus be examined.

CNV and P3: A number of investigators (Donchin and Smith, 1970; Karlin, 1970; Naatanen, 1967, 1975; Wilkinson and Ashby, 1974) have postulated that the prior CNV and P3 are closely related. The essence of these arguments was presented earlier in the P2 discussion. Some studies have indeed found that as the CNV increases in negativity P3 increases in positivity (Hillyard et al., 1971). Picton and Low (1971), although finding a relationship between P3 amplitude evoked to confirming feedback and CNV, nevertheless said they changed independently. Conversely other investigators have found dissociation between the two (Donald and Goff, 1971; Donchin et al., 1975; Friedman et al., 1973; Jenness, 1972a;

Poon et al., 1974; Tueting and Sutton, 1973). It has also been established that CNVs with equal amplitude can be followed by P3s with different amplitudes depending on the nature of the experimental manipulation.

In the present study, only one consistent CNV-P3 relationship was manifested. Over the three days, the CNV and P3 both increased in amplitude. The CNV daily data as mentioned above is consistent with Low and Swift's (1971) findings. The same trend for P3, however, is different from Tueting et al's. (1971) findings of an opposite effect -- a decrease in P3 over the days of her experimentation. If the decreased P3 over time was due to habituation, then it is apparent that subjects in the present study did not habituate to the feedback stimuli even though by the end of the third day of experimentation they had perceived more than 1000 of them. An hypothesis centered on decreased anxiety could account for the covariation between the CNV and P3. Other than this exception, no other common traits were observed.

Several incongruencies were however exhibited. Firstly, the very low correlation between CNV and P3 over the entire study suggested that rather than displaying covariation, the two appeared orthogonal. Secondly, P3 was significantly affected by a number of the experimental manipulations. CNV was not. CNV, in fact, was large in the control conditions, P3 being at its smallest. Finally,the CNV was parietal dominant in association with the preparation for reception of a visual input. P3,while also parietal dominant,showed strong frontal influences - particularly for disconfirming feedback.

The differential preparation argument runs into a severe barrier when prior knowledge of post-stimulus events is precluded. Hence in the experimental situation, regardless of event outcome, of which the subject has no knowledge, the subject's preparatory set or priming prior to reception of a particular feedback stimulus should be the same. This formulation appears to fit the data. Under disparate conditions, for example, significant P3 differences were found between the effects of confirming and disconfirming feedback while CNV failed to be altered. Based on these and other evidence presented in the literature, particularly the compelling factor analytic results of Donchin et al. (1975), the view that differential CNV amplitudes could bias the ensuing LPC data appears most inadequate and weak.

Reactive change of state: A stronger noncognitive interpretation has been raised by Karlin (1970) and Wilkinson and Ashby (1974) based on post- rather than pre-stimulus events. When differential preparation is precluded because advance information is not provided about which type of stimulus will occur, P3 may still be modified because the subject responds differentially to the types of feedback. "This differential response consists of a change in state in which level of arousal is most likely reduced because... the subject starts to relax as a result of task completion in response to the relevant stimulus" (Karlin, 1970, p.134). According to this argument,to account for the direct relationship between the task relevant information content of the stimulus and the enhancement of P3, one must assume that subjects "relaxed" most upon reception of the highly informative stimuli. Such momentary relaxation would seem incongruent with the Luria-Pribram hypothesized demands of feedback. Feedback,in its calling for re-programming and re-testing of prior hypotheses leading to a correction of past events,invokes wide cortical activity or arousal -- not relaxation.

On Day 2 of the present study, monetary incentive appeared to act in the role of a motivator to decrease error responses as evidenced by the improved accuracy of estimation. Over the three days of experimentation then, it would be expected that with the extra "push" provided by the payoffs, a rise in the level of cortical arousal would follow. In keeping with the Karlin point of view, at the moment of the feedback signal, the momentary drop in arousal (and hence enhancement of P3) should have been particularly evident. However, P3 was smaller on Day 2 than on Day 3, when no incentive was provided. Moreover on Day 2, a drop in P3 amplitude did not occur with the no incentive condition, a period when subjects likely manifested a decrease in arousal.

An alternate post-stimulus hypothesis based on resolution of the CNV occurring around 300 ms after stimulus onset does appear to have some support (Naatanen, 1975; Wilkinson and Ashby, 1974). The fact that P2 and P3 showed some degree of common variance in this and other experiments (Adams and Benson, 1973; Friedman et al., 1973; Poon et al., 1976) suggests that an underlying positive movement may have been active during or soon after N1 onset. Two pieces of evidence support this CNV falloff proposal ; first, the amplitude of P2 was rather large (ranging up to 20 μV) considering the low intensity of the LEDs and the attenuated amplitude of the N1 component,hinting at an overlap with the P3 process. The correlation between P2 and P3 indicated that they were not entirely independent of one another; secondly, N2 had an inverse relationship to both P2 and P3, a finding also reported by Friedman et al. (1973) and Tueting et al. (1971), being drawn below baseline (negative upwards) by the continuance of positivity. In some reports (Paul and Sutton, 1972; Squires et al., 1973b; Stuss et al., 1976), N2 is entirely lacking,producing a composite P2-P3 wave. Therefore,the unusually large amplitude positive components,in association with rather small negative ones,suggest an underlying "baseline" of DC activity that provides an environment for the expression of positive-going,but a depression of negative-going activity.

P3 is however distinct from P2 in several aspects. There is little doubt that the two are correlated with regard to response to irrelevant feedback signals. They are differentiated by P3's variable responsiveness to amounts of relevant information. P2 thus might be the first stage in the processing of relevant information. If the information is irrelevant, no further processing is required; if the stimulus is relevant, second and possibly further stages of processing are called into play as demonstrated by the P3 and P4 peaks.

Surprisal: One of the most frequently cited formulations concerning P3 magnitude is that it is present with the delivery of task relevant, salient information that resolves prior uncertainty concerning the nature of the stimulus (Sutton et al., 1965; Sutton et al., 1967). In a detailed testing of this hypothesis, Friedman et al. (1973), Ruchkin et al. (1975) and Tueting et al. (1971) presented evidence that P3 varied indirectly with stimulus probability. The greater the *a priori* uncertainty of the subject concerning a particular event, the greater was the amplitude of P3 upon onset of that event. "In other words, P3 amplitude seems to be determined by the degree of 'unexpectedness' of the outcome" (Tueting et al., 1971, p.391). In the present study, uncertainty was defined as "surprisal" following information theory techniques. In Experiment 1-1 surprisal did not appear to play a major role in the determination of P3 amplitude. For example, some of the irrelevant stimuli were more surprising than the relevant feedback, yet P3 was greatly attenuated. Differences due to surprisal with the relevant stimuli were difficult to assess due to the confounding effects of what was defined as the task relevant information content. Experiments 3-1 and 3-2 were thus specifically designed to separate out the effects of surprisal and task relevant information. Once again,regardless of how surprising irrelevant stimuli were, the effect on P3 was minimal. Moreover,when disconfirming feedback contained equal amounts of task relevant information but varied on the degree of surprisal, the latter had little influence on P3 magnitude. Unpredictability or surprisal then is not a necessary condition for the enhancement of P3.

Orienting response, template-matching, decision complex: In the Smith et al. (1970) study, P3 was delivered when some decision about the nature of the stimulus had to be made. Consistent with the decision-processing theory are data showing that P3 can be elicited by the absence of a stimulus as much by its presentation (Barlow, 1969; Picton et al., 1974a; Ruchkin et al., 1975; Simson et al., 1976; Weinberg et al., 1970).

Several related studies pointed out that the perceptual decision entailed matching attended inputs to a neuronal model or template, P3 representing the additional perceptual and cognitive processing called on to evaluate the significance of the "orienting response" (Ritter et al., 1968; Ritter and Vaughan, 1969; Corby and Kopell, 1973). Picton and Hillyard based their model on Broadbent's proposal of two types of selective attention. The first reflects stimulus set (P2 in the present study, N1 in the Picton and Hillyard study) which filters out irrelevant information. The second component, response set, is the perceptual decision complex as indexed by P3. It entails the matching of inputs to a template so that target stimuli signalling required, important, and improbable response could be detected.

With feedback paradigms the difference between "correct" and "incorrect" is obvious. Squires thus proposed an alternate mechanism:

> In the first, "template-matching" stage, stimulus input is analyzed with reference to the particular template specifications, and an output proportional to the match is led to the second "decision" stage. Here, the output from the template stage is added to a "bias" level that is set in advance according to the S's expectancy that the signal will occur (p.29).

This model, partially at least, appears to fit the data adequately. The "analysis with reference to template specifications" seems to reflect P2 functioning. A template or model of confirmation and disconfirmation is likely established, relevant stimuli matching these models, hence the large P2 waves. Moreover descriptions of the orienting P3 or P3a place its latency well within the range of P2's 240-250 ms (Ford et al., 1976; Roth, 1973; Squires, N. et al., 1975). However, because the subject has prior awareness of the degree of relevancy of the feedback stimulus, P2 activity cannot be described as an orienting response. The second stage of Squires' model is based on the subject's confidence related to the prior decision, a concept earlier developed by Hillyard. "The P300 wave indexes the observer's degree of confidence or certainty that a signal had occurred" (Hillyard et al., 1971, p.1359). Confidence or certainty in feedback studies refers to the pre-stimulus period, whereas in Hillyard et al's. study degree of confidence refers to a post-stimulus interval. In the discrimination situation, the stimulus itself constitutes a source of post-stimulus uncertainty while with feedback, the stimulus may be said to resolve the subject's pre-stimulus uncertainty. Confidence thus was not considered in this experiment since the subject was always confident as to the occurrence of the stimulus. Ruchkin and Sutton (in press) have quite recently offered another formulation related to the above mentioned confidence propositions. The amount of information received by the subject equals the information provided by the event minus an information loss related to the subject's *a posteriori* uncertainty of having correctly perceived the event; the greater the *a posteriori* uncertainty, the greater the information loss. The authors borrow the term "equivocation" from information theory to describe this phenomenon.

Motivation or involvement: Paul and Sutton (1972) and Sutton et al. (1965) reported that when a task involves monetary payoff, P3 is larger for larger payoffs. In both cases, however, payoff was not independent of probability. In the case of the signal detection paradigm, different payoff matrices were employed as a means of manipulating the subject's criterion for responding. It is noteworthy that Paul and Sutton considered the amount of payoff, which ranged up to nine cents, adequate to induce motivation. Similar payoffs were adopted with similarly chosen subjects for this study.

Poon et al. (1974) found that when subjects' payoff was maximum (i.e., when errors were minimal), P3 dramatically decreased. Again, however, probability/information could have confounded the results. Sutton (personal communication with T. Picton) noted that the increase in P3 is greatest when the subject himself chooses the value of the guess, suggesting some index of "involvement" or what Squires et al. (1973a) termed "committment". In this context, however, "involvement" was related to confidence of the decision.

In the present study, independent of surprisal, incentive appeared to have almost no effect on P3. Even when the stakes were such as to weight one particular stimulus disproportionally, no effect was found. It might be that the monetary incentive was in fact not motivating -- subjects, in Sutton's terminology, were not more involved with the task. As mentioned above, similar payoffs in previous studies were considered to induce greater subject motivation. In addition, the improved performance of subjects as indicated by increased accuracy of estimation suggests that level of motivation was manipulated. Sutton (1969) has proposed that monetary payoffs create multiple options for the subject. In some situations, for example, the frustration at losing a dime might have been counterbalanced by the relief of no loss (yet no gain) obtained with a correct judgement.

Information processing complexity: A final concept of P3 (Donchin et al., 1973) suggests that it reflects the "general activity of a general purpose processor which is invoked on demand by a host of data requirements" (p.323). It was deemed analagous to the stringency and accuracy brought about by informational complexity. The vagueness of this model has led some authors (e.g., Ruchkin and Sutton, in press) to precisely define information processing terms following information theory, thus the term "equivocation". Equivocation can be thought of in terms of the "immediacy and ease" with which a decision can be made, increased equivocation leading to decreases in P3 amplitude.

An important issue raised by Donchin et al. is that the P3 is not the output of cognitive processing as Squires et al. and other "template-matching" theorists suggest, but rather is a measure of ongoing cognitive activity itself. In this context Donchin (personal communication with T. Picton, 1976) believes that cognitive evaluation of feedback related activity is related to modifications that will be reflected in decisions in future trials. "The sensitivity of P300 to probability [task relevant information] could reflect the greater need for re-adjustment following the presentation of a rare highly informative event" (Donchin, correspondence with P. Tueting, 1976).

In view of the direct correlation found between P3 amplitude and task relevant information content, some degree of support for the Donchin hypothesis was indicated. Although a 20% decrease in amplitude was apparent with lowly informative disconfirming signals on Day 3 compared to the highly informative confirming signals, the analysis of variance failed to point to a significant difference. A major statistical problem associated with small sample sizes is power, power being defined as the ability to reject the null hypothesis when in fact it should be rejected (Campbell and Stanley, 1968). As well the ANOVA technique, which is markedly affected by the inter-subject variability common in evoked potential research, may not have been sensitive to the amplitude changes associated with small increases or decreases in informational content. For these reasons a correlative technique was applied.

It is believed that this is the first study to study the relationship between stimulus complexity, defined in terms of bits of information, and the amplitude of the late components of the evoked potential. The correlation between the degree of task relevant information contained in the stimulus and P3 amplitude was very high. The scattergram of the data suggested the possibility of a curvilinear relationship with P3 levelling off with higher amounts of information. In spite of this good relationship, it is difficult to determine whether this reflects ongoing cognitive activity or output from this processing. Moreover as mentioned, Donchin et al.'s terminology is somewhat general, making specific conclusions hazardous. In Experiment 2-1, when informational content was equal for all stimuli, disconfirming feedback consistently evoked P3s approximately 5 to 10% larger than confirming feedback. This difference, however, failed to reach statistical significance. Interpretations related to confirming/disconfirming effects when the amount of task relevant information is the same must remain cautious at best.

In most studies, therefore, disconfirming feedback have evoked large P3s because their informational processing demands are such as to produce widespread corrective behaviour, comparing what was planned with what in fact actually took place. A "plan of action" (Anokhin, 1969) or perceptual trace of the time percept is assumed in order to allow for comparison mechanisms. Closed-loop theorists have traditionally made provisions for such internal representations although different terminology have been applied. For Tolman (1932), the trace was called a "cognitive map", for Mandler (1962), a "symbolic analogue" of the habit was generated, it being somewhat similar to Piaget's (1958) "schema".

Latency and topography: The failure to find latency effects associated with any of the independent variables is perplexing. It was expected that disconfirming feedback would require longer processing than confirming (Squires et al., 1973a). Behavioural data offer tentative rationale. Erikson, Zajkowski, and Ehman (1966) demonstrated that response latencies on error trials and correct trials are not different but latencies after error trials are greater than latencies after correct trials. In their study, error was more informative than confirmation. Had the physiological data been analyzed in this manner, i.e., averaging the trials immediately following correct or incorrects estimations, latency differences might possibly have been found. Squires, Wickens, Squires, and Donchin (in press) have in fact inspected waveform statistics according to sequence of stimulus presentations. Their results showed that P3 was remarkably sensitive to trial-to-trial variations in the sequence of events preceding the eliciting event. A stimulus elicited a larger P3 if preceded by more of the same than if preceded by different stimuli. Data related to latency changes were not mentioned.

Courchesne et al. (1975), Hillyard et al. (1975), Picton and Hillyard (1974), Poon et al. (1976), and Ritter, Simson, and Vaughan (correspondence with P. Tueting, 1976) based on multi-channel recordings of a number of response contingencies have indicated that while P3 is mainly a parietocentral phenomenon, there are notable exceptions to the rule. The distribution maps of the present study indicated that although P3 was largest parietally, the Cz and especially Fz recording sites showed more differences between conditions than did Pz. Almost identical findings were reported by Poon et al. (1976). Moreover disconfirmation evoked significantly larger frontal waves than confirmation. This latter finding appears unique, neither Hillyard et al. (1975), nor Poon et al. (1974, 1976) having mentioned it.

The frontal P3 has thus been related to at least three psychological events: orientation to novel stimuli (Courchesne et al., 1975), the "no-go" response (inhibition of response in a go/no-go reaction time task (Hillyard et al., 1975; Ritter et al., in press), and response to feedback especially if the feedback informs the subject of error (Hillyard et al., 1975; Poon et al., 1976). The feedback response does not appear related to either the orienting or the no-go response, suggesting that the frontal P3 does not represent a single unitary underlying phenomenon.

The frontal lobe has been conceptualized as being concerned with mechanisms of vigilance and monitoring for significant events (Luria, 1966a, 1966b; Pribram, 1969). Soviet formulation (Anokhin, 1969; Vygotsky, 1932) have related feedback to verbal processing and not monitoring or vigilance, thus explaining the frontal P3 activity.

Das et al.'s (1975) model for cognitive activity proposes that after initial sensory registration, information is then "read out" into what is called the central processing unit. This central processing unit corresponds well with Donchin et al's. schema of P3 cognitive related activity. For Das and his associates, central processing may be of two types, the successive type seen in the frontal lobes or the simultaneous type in the parietal-occipital areas. Hence the widespread P3 may reflect both modes of processing -- planning and re-evaluation in association with speech in frontal zones and integration of diverse information in posterior regions.

P4 A still later positive peak, P4, has only recently been described (Cael et al., 1974; Jenness, 1972a), its significance or relationship to experimental events however receiving little attention. In this study, P4, like the earlier positive peaks, P2 and P3, was influenced by task relevant feedback. It covaried with informational loading but the relationship was not nearly as clear as was the corresponding case with P3. The correlation between P3 and P4 centrally indicated that it (P4) was not entirely independent from P3. Nevertheless,it significantly differed from P3 in its Pz/Fz ratio, P3 being much more widespread than P4 which was largely based in parietal zones. Anterior to posterior flow of positivity fits well into Nauta's (1972) model and has recently been suggested by Renaud and Lesèvre (in press).

P4 has recently been hypothesized to reflect the utilization of feedback evaluation (P3) for future performance (Stuss et al., 1976). Taken in this light, the strong parietal dominance of P4 suggests that it indexes an integration of diverse information,perhaps arising from frontal zones in preparation for future events.

The existent data on P4 does not permit anything but tentative proposals concerning its nature. It is puzzling that not more than a handful of studies have observed it. If it is unique to the feedback situation why was it not seen more frequently in the literature (e.g., Benson and Teas, 1972; Nielsen et al., 1970; Picton and Low, 1971; Poon et al., 1974)? It may be that it is present only when the task is of sufficient complexity as to allow feedback to be employed for comparing the events of the past in a type of memory search (Roth et al., 1975) and correcting the consequences.

The independence of P3 and P4 at the moment is not firmly established, the sole basis being topographical distinctions. In some individuals P4 appeared as a continuous wave with P3, while in others it was hardly at all apparent. Squires, N. et al. (1975) identified what was called a slow wave (SW) as opposed to a sharp peak following P3. The authors have reported that the SW, like P4, is more negative-going frontally and becomes more positive-going parietally. Wilkinson and Ashby (1974), finding positive components as late as 400 and 500 ms after stimulus onset, suggested that P3 might under many conditions form only a part of a longer duration positive response. The SW like P4 has been reported to be less positive frontally and to become progressively more positive-going parietally.

Assuming that the trigger for P4 is internal and considering the lateness of its onset, one would expect considerable variability in latency across conditions in averages time-locked to stimulus presentations. Ritter et al. (1972) for example found that variation in parietal P3 latency from trial-to-trial correlated with trial-to-trial variation in reaction time. If P3 latency is this modifiable, P4 should be even more so. In fact the relatively small amplitude of P4 in comparison to P3 and in some cases its complete absence may have been due to high latency variability and not because of a real absence or attenuation of P4 response. One solution to the problem would require the obtaining of latency and amplitude records on a trial-by-trial basis. This, although more difficult to do for small amplitude components, may be a possibility for P3 or P4 which can be quite large on individual trials in response to feedback. The technical problems involved in defining components on individual trials are considerable. Nevertheless, CNV researchers (Weinberg and Cooper, 1972a, 1972b) have successfully employed such a procedure, based on a variation of cross-correlational statistics to identify similar wave forms. Ruchkin (correspondence with P. Tueting, 1976) is presently using Woody Filter Analysis (Woody, 1967) which also requires an interactive correlational procedure as a basis for realigning single trials before latency corrected averaging. Even so, the signal to noise ratio must be relatively large -- greater than 1.6 (personal communication with T. Picton, 1976).

Certain possible determinants of P3 were not investigated such as confidence of the decision (Hillyard et al., 1971; Squires et al., 1973a) and personality of the subject (Jenness, 1972a;Poon et al., 1974).

Summary

1. CNV increases in negativity from Day 1 to Day 3 probably due to a decrease in anxiety. Low and Swift (1971) found similar results as subjects became familiar with task procedures. It, however, showed little relationship to post-stimulus events such as P3.

2. The effects of task relevant information were noted as early as P2, perhaps indicative of an initial stage of information processing. P2, however, was unaffected by experimental manipulations.

3. P3 correlated most highly with the amount of task relevant information contained in the stimulus and not with stimulus surprisal or unexpectedness.

4. Disconfirmation evokes P3 peaks that are significantly larger frontally than in the case of confirmation.

5. P3 is unaffected by a variety of monetary incentives assigned to specific feedback signals, suggesting that it is unrelated to prior states of arousal.

6. There was a tendency for suppression of negative activity in favour of positive-going components (P2, P3 and P4). There are, however, differences between these components based on experimental manipulations and scalp topography. P4 was much more parietal dominant than P3 and showed significantly less frontal activity.

Reference Notes

1. Annett, J., & Paterson, L. The use of cuing in training tasks: phase II. U.S. Navy Report, NAVTRA-DECEN, 4119-4121, 1966.

2. Donchin, E. Personal communication with T. Picton, April, 1976.

3. Ruchkin, D.S. Personal communication with T. Picton, April, 1976.

4. Sutton, S. Personal communication with T. Picton, April, 1976.

References

Adams, J.A. Response feedback and learning. Psychological Bulletin, 1968, 70, 486-504.

Adams, J.A. A closed-loop theory of motor learning. Journal of Motor Behavior, 1971, 3, 111-149.

Adams, J.A., & Bray, N.W. A closed-loop theory of paired-associate verbal learning. Psychological Review, 1970, 77, 385-405.

Adams, J.C., & Benson, D.A. Task-contingent enhancement of the auditory evoked response. Electroencephalography and Clinical Neurophysiology, 1973, 35, 249-257.

Ammons, R.B. Effects of knowledge of results -- a survey and tentative theoretical formulation. Journal of General Psychology, 1956, 54, 279-299.

Annett, J. Feedback and Human Behaviour. Harmondsworth, Middlesex: Penguin, 1969

Anokhin, P.K. A new conception of the physiological architecture of conditioned reflex. In J.F. Delafresnaye (Ed.), Brain mechanisms and learning. Springfield, Ill.: Charles C. Thomas, 1961.

Anokhin, P.K. Cybernetics and the integrative activity of the brain. In M. Cole & I. Maltzman (Eds.), A handbook of contemporary Soviet psychology. New York: Basic Books, 1969.

Attneave, F. Applications of information theory to psychology: a summary of basic concepts, methods, and results. New York: Holt, Rinehart, and Winston, 1959.

Averbach, E., & Sperling, G. Short-term storage of information in vision. In C. Cherry (Ed.), Symposium on information theory. London: Butterworth, 1961.

Baker, C.H., & Young, P. Feedback during training and retention of motor skills. Canadian Journal of Psychology, 1960, 14, 257-264.

Barlow, J.S. Some observations on the electrophysiology of timing in the nervous system. Electroencephalography and Clinical Neurophyscology, 1969, 27, 545.

Beck, E.C. Electrophysiology and behavior. Annual Review of Psychology, 1975, 26, 233-262.

Benson, D.A., & Teas, D.C. Human auditory-evoked response: specific effects of signal strength and performance criterion. Perception and Psychophysics, 1972, 11, 203-208.

Bernstein, N. The coordination and regulation of movement. New York: Pergamon, 1967.

Bilodeau, E.A. Acquisition of skill. New York: Academic, 1966.

Bilodeau, E.A., & Bilodeau, I. McD. Variable frequency of knowledge of results and the learning of a simple skill. Journal of Experimental Psychology, 1958, 55, 379-383.

Bilodeau, E.A., Bilodeau, I. McD. & Schumsky, D.A. Some effects of introducing and withdrawing knowledge of results early and late in practice. Journal of Experimental Psychology, 1959, 58, 142-144.

Bilodeau, E.A., & Rosenbach, J.H. Acquisition of response proficiency as a function of rounding error in informative feedback. HRRC Research Bulletin, 1953, 53-121.

Borda, R.P. The effects of altered drive states on the contingent negative variation in monkeys. Electroencephalography and Clinical Neurophysiology, 1970, 29, 173-180.

Boulter, L.R. Evaluation of mechanisms in delay of knowledge of results. Canadian Journal of Psychology, 1964, 18, 281-291.

Briggs, G.E., Fitts, P.M., & Bahrick, H.P. Learning and performance as a function of transfer task complexity. Journal of Experimental Psychology, 1957, 53, 379-387.

Broadbent, D.E. Perception and Communication. London: Pergamon Press, 1958.

Broadbent, D.E. Decision and Stress. London: Academic, 1971.

Broughton, R., Rasmussen, T., & Branch, C. Cortex and scalp recorded somatosensory evoked potentials in man. Electroencephalography and Clinical Neurophysiology, 1968, 24, 285.

Buckner, D.N., & McGrath, J.J. Vigilance: A Symposium. New York: McGraw-Hill, 1963.

Butler, R.A. Frequency specificity of the auditory evoked response to simultaneously and successively presented stimuli. *Electro-encephaolgraphy and Clinical Neurophysiology*, 1972, *33*, 277-282.

Cael, W.W., Nash, A., & Singer, J.J. The late positive components of the human EEG in a signal detection task. *Neuropsychologia*, 1974, *12*, 385-387.

Campbell, D.T., & Stanley, J.C. *Experimental and Quasi-Experimental Designs*. Chocago: Rand McNally, 1966.

Cant, B.R., & Bickford, R.G. The effect of motivation on the contingent negative variation (CNV). *Electroencephalography and Clinical Neurophysiology*, 1967, *23*, 594.

Chapman, R.M. Evoked responses to relevant and irrelevant visual stimuli while problem solving. *Proceedings of the American Psychological Association*, 1965, *1*, 177-178.

Chapman, R.M., & Bragdon, H.R. Evoked responses to numerical and non-numerical visual stimuli while problem solving. *Nature*, 1964, *203*, 1155-1157.

Chase, R.A. An information-flow model of the organization of motor activity. I: Transduction, transission and central control of sensory information. *Journal of Nervous and Mental Disease*, 1965, 140, 239-251 (a).

Chase, R.A. An information-flow model of the organization of motor activity. Part II: Sampling, central processing, and utilization of sensory information. *Journal of Nervous and Mental Disease*, 1965, *140*, 334-350 (b).

Cochran, W.G., & Cox, G.M. *Experimental designs* (2nd ed.) New York: Wiley, 1957.

Cohen, J. Very slow potentials relating to expectancy: the CNV. In E. Donchin & D.B. Lindsley (Eds.), *Average evoked potentials: Methods, results, and evaluations.* (NASA SP-191). Washington, D.C.: U.S. Government Printing Office, 1969.

Cohen, J., Offner, F., & Blatt, S. Psychological factors in the production and distribution of the contingent negative variation (CNV). *Proceedings of the International Congress of Electro-encephalography and Clinical Neurophysiology, Vienna*. Amsterdam: Elsevier, 1965, 251-254.

Cohen, J., Offner, F., & Palmer, C.W. Development of the contingent negative variation in children. Electroencephalography and Clinical Neurophysiology, 1967, 23, 77-78.

Cohen, J., & Walter, W.G. The interaction of responses in the brain to semantic stimuli. Psychophysiology, 1966, 2, 187-196.

Connor, W.H., & Lang, P.J. Cortical slow-wave and cardiac rate responses in stimulus orientation and reaction time conditions. Journal of Experimental Psychology, 1969, 82, 310-320.

Cooper, R., Winter, A.L., & Crow, H.J., & Walter, W.G. Comparison of subcortical, cortical, and scalp activity using chronically indwelling electrodes in man. Electroencephalography and Clinical Neurophysiology, 1965, 18, 217-228.

Corby, J.C., & Kopell, B.S. The effect of predictability on evoked potential response enhancement in intramodal selective attention. Psychophysiology, 1973, 10, 335-346.

Courchesne, E., Hillyard, S.A., & Galambos, R. Stimulus novelty, task relevance, and the visual evoked potential in man. Electroencephalography and Clinical Neurophysiology, 1975, 39, 131-143.

Das, J.P., Kirby, J., & Jarman, R.F. Simultaneous and successive synthesis: An alternate model for cognitive abilities. Psychological Bulletin, 1975, 82, 87-103.

Davis, H. Enhancement of evoked cortical potentials in humans related a task task requiring a decision. Science, 1964, 145, 182-183.

Davis, M., & Heninger, G.R. Comparison of response plasticity between the eyeblink and vertex potential in humans. Electroencephaolography and Clinical Neurophysiology, 1972, 33, 283-293.

Davis, H., Mast, T., Yoshie, N., & Zerlin, S. The slow response of the human cortex to auditory stimuli: Recovery processes. Electroencephalography and Clinical Neurophysiology, 1966, 21, 105-113.

Davis, H. & Zerlin, S. Acoustic relations of the human vertex potential. Journal of the Acoustical Society of America, 1966, 39, 109-116.

Dawson, C. A summation technique for the detection of small evoked potentials. Electroencephalography and Clinical Neurophysiology, 1954, 6, 65-84.

Dickman, K. SOUPAC program descriptions, DCL Report No. UIUCDCS-R-72-370-4. University of Illinois, 1972.

Deecke, L., Scheid, P., & Kornhuber, H.H. Distribution of readiness potential, pre-motion positivity, and motor potential of the human cerebral cortex preceding voluntary finger movements. Experimental Brain Research, 1969, 7, 158-168.

Delse, F.C., Marsh, G.R., & Thompson, L.W. CNV correlates of task difficulty and accuracy of pitch discrimination. Psychophysiology, 1972, 9, 53-62.

Domino, E.F., Matsuoka, S., Waltz, J., & Cooper, I.S. Simultaneous recordings of scalp and epidural somato-sensory evoked responses in man. Science, 1964, 145, 1119-1200.

Donald, M.W., & Goff, W.R. Attention related increases in cortical responsivity dissociated from the contingent negative variation. Science, 1971, 172, 1163-1166.

Donchin, E. A multivariate approach to the analysis of average evoked potentials. IEEE Transactions Bio-Medical Engineering, 1966, BME-13, 131-139.

Donchin, E. Data analysis techniques in average evoked potential research. In E. Donchin and D.B. Lindsley (Eds.), Average evoked potentials: Methods, results, and evaluations. (NASA SP-191). Washington, D.C.: Government Printing Office, 1969.

Donchin, E., & Cohen, L. Averaged evoked potentials and intramodality selective attention. Electroencephalography and Clinical Neurophysiology, 1967, 22, 537-546.

Donchin, E., & Cohen, L. Anticipation of relevant stimuli and evoked potentials: A reply to Naatanen. Perceptual and Motor Skills, 1969, 29, 115-117.

Donchin, E., Gerbrandt, L.K., Leifer, L., & Tucker, L. Is the contingent negative variation contingent on a motor response? Psychophysiology, 1972, 9, 1163.

Donchin, E., Kubovy, M., Kutas, M., Johnson, R., & Herning, R.I. Graded changes in evoked response (P300) amplitude as a function of cognitive activity. Perception and Psychophysics, 1973, 14, 319-324.

Donchin, E., Otto, D., Gerbrandt, L.K., & Pribram, K.H. While a monkey waits: Electrocortical events recorded during the foreperiod of a reaction time study. Electroencephalography and Clinical Neurophysiology, 1971, 31, 115-128.

Donchin, E., & Smith, D.B.D. The contingent negative variation and the late positive wave of the evoked potential. Electroencephalography and Clinical Neurophysiology, 1970, 29, 201-203.

Donchin, E., Tueting, P., Ritter, W., Kutas, M., & Heffley, E. On the independence of the CNV and the P300 components of the human evoked potential. Electroencephalography and Clinical Neurophysiology, 1975, 38, 449-461.

Eason, R.G., Harter, M.R., & White, C.T. Effects of attention and arousal on visually evoked cortical potentials and reaction time in man. Physiology and Behavior, 1969, 4, 283-289..

Elwell, J.L., & Grindley, G.C. Effect of knowledge of results on learning and performance. British Journal of Psychology, 1938, 29, 39-54.

Erikson, J.R., Zajkowski, M.M., & Ehmann, E.D. All-or-none assumptions in concept identification: Analysis of latency data. Journal of Experimental Psychology, 1966, 72, 690-697.

Fairbanks, G. Systematic research in experimental phonetics: A theory of the speech mechanism as a servosystem. Journal of Speech and Hearing Disorders, 1954, 19, 133-139.

Ford, J.M., Roth, W.T., & Kopell, B.S. Auditory evoked potentials to unpredictable shifts in pitch. Psychophysiology, 1976, 13, 32-39.

Friedman, D., Hakerem, G., Sutton, S., & Fleiss, J.L. Effect of stimulus uncertainty on the pupillary dilation response and the vertex evoked potential. Electroencephalography and Clinical Neurophysiology, 1973, 34, 475-484.

Frustorfer, H. Habituation and dishabituation of the human vertex response. Electroencephalography and Clinical Neurophysiology, 1971, 30, 306-312.

Frustorfer, H., & Bergstrom, R.M. Human vigilance and auditory evoked responses. Electroencephalography and Clinical Neurophysiology, 1969, 27, 346-355.

Garcia-Austt, E. Influence of the states of awareness upon sensory evoked potentials. Electroencephalography and Clinical Neurophysiology, 1963, 24 (Supplement), 76-90.

Garcia-Austt, E., Bogacz, A., & Vanzulli, A. Effects of attention and inattention upon visual evoked response. Electroencephalography and Clinical Neurophysiology, 1964, 17, 136-143.

Geisser, S., & Greenhouse, S.W. An extension of Box's results on the use of F distribution in multivariate analysis. Annals of Mathematical Statistics, 1958, 29, 885-891.

Gerbrandt, L.K., Goff, W.R., & Smith, D.B. Distribution of the human average movement potential. Electroencephalography and Clinical Neurophysiology, 1973, 34, 461-474.

Gilden, L., Vaughan, H.G., Jr., & Costa, L.D. Summated human EEG potentials with voluntary movement. Electroencephalography and Clinical Neurophysiology, 1966, 20, 433-438.

Goff, W.F. Human average evoked potentials: Procedures for stimulating and recording. In R.F. Thompson and M.M. Patterson (Eds.), Bioelectric recording techniques Part B: Electroencephalography and human brain potentials. New York: Academic, 1974.

Goff, W.R., Matsumiya, Y., Allison, T., & Goff, G.D. Cross-modality comparisons of average evoked potentials. In E. Donchin and D.B. Lindsley (Eds.), Average evoked potentials: Methods, results and evaluations. (NASA SP-191). Washington, D.C.: Government Printing Office, 1969.

Green, D., & Swets, J. Signal detection theory and psychophysics. New York: Wiley, 1966.

Greenwald, A.G. Sensory feedback mechanisms in performance control: With special reference to the ideo-motor mechanism. Psychological Review, 1970, 70, 73-99.

Greenwald, A.G. Within-subject designs: To use or not to use? Psychological Bulletin, 1976, 83, 314-320.

Gross, M.M., Begleiter, H., Tobin, M., & Kissen, B. Auditory evoked response comparison during counting clicks and reading. Electroencephalography and Clinical Neurophysiology, 1965, 18, 451-454.

Gullickson, G.R. The contingent negative variation in the preschool child. Dissertation Abstracts, 1970, 31, 3022B.

Haider, M., Groll, E., & Studynka, G. Orienting and readiness potentials with unexpected stimuli. *Experimental Brain Research*, 1968, *5*, 45-54.

Haider, M., Spong, P. & Lindsley, D.B. Attention, vigilance and cortical evoked potentials in man. *Science*, 1964, *145*, 180-182.

Harter, M.R., & Salmon, L.E. Intra-modality selective attention and evoked cortical potentials to randomly presented patterns. *Electroencephalography and Clinical Neurophysiology*, 1972, *32*, 605-613.

Hartley, L.R. The effects of stimulus relevance on the cortical evoked potentials. *Quarterly Journal of Experimental Psychology*, 1970, *22*, 531-546.

Harton, J.J. An investigation of the influence of success and failure on the estimation of time. *Journal of General Psychology*, 1939, *2*, 51-62.

Heath, R.G., & Galbraith, G.C. Sensory evoked responses recorded simultaneously from human cortex and scalp. *Nature*, 1966, *212*, 1535-1537.

Hernandez-Pēon, R., & Donoso, C.M. Influence of attention and suggestion upon subsortical evoked electrical activity in the human brain. In L. van Bogaert and J. Radermecker (Eds.), *First international congress of neurological sciences*. New York: Pergamon Press, 1959.

Hillyard, S.A. The CNV and the vertex evoked potential during signal detection: A preliminary report. In E. Donchin & D.B. Lindsley (Eds.), *Average evoked potentials: Methods, results, and evaluations.* (NASA SP-191). Washington, D.C.: U.S. Government Printing Office, 19691.

Hillyard, S.A. Methodological issues in CNV research. In R.F. Thompson & M.M. Patterson (Eds.), *Bioelectric recording techniques. Part B: Electroencephalography and human potentials*. New York: Academic, 1974.

Hillyard, S.A. Courschesne, E., Krausz, H.I., & Picton, T.W. Scalp topography of the "P3" wave in different auditory decision tasks. In W.C. McCallum & J.R. Knott (Eds.), *Event-related slow potentials of the brain*. Bristol: John Wright and Sons, 1975.

Hillyard, S.A. & Galambos, R. Eye movement artifact in the CNV. Electroencephalography and Clinical Neurophysiology, 1970, 28, 173-182.

Hillyard, S.A., Hink, R.F. Schwent, V.L., & Picton, T.W. Electrical signs of attention in the human brain. Science, 1973, 182, 177-180.

Hillyard, S.A., Squires, K., Bauer, J., & Lindsay, P. Evoked potential correlates of signal detection. Science, 1971, 172, 1357-1360.

Hirsh, S.K. Vertex potentials associated with an auditory discrimination. Psychonomic Science, 1971, 22, 173-175.

Hornstein, A.D., & Rotter, G.S. Research methodology in temporal perception. Journal of Experimental Psychology, 1969, 79, 561-564.

Irwin, D.A., Knott, J.R., McAdam, D.W., & Rebert, C.S. Motivational determinants of the "contingent negative variation". Electroencephalography and Clinical Neurophysiology, 1966, 21, 538-543.

James, W. The principles of psychology (Vol. 1). New York: Holt, 1890.

Jarvilehto, T., & Frustorfer, H. Differentiation between slow cortical potentials associated with motor and mental acts in man. Experimental Brain Research, 1970, 11, 309-317.

Jenness, D.A. Auditory evoked-response differentiation with discrimination learning in humans. Journal of Comparative and Physiological Psychology, 1972, 80, 75-90, (a).

Jenness, D.A. Stimulus role and gross differences in the cortical evoked response. Physiology and Behavior, 1972, 9, 141-146 (b).

Jouvet, M., Schott, B., Couyon, J., & Allègre, G. Documents neurophysiologiques relatifs aux mechanismes de l'attention et le conditionnement. Revue de Neurologie, 1959, 100, 437-450.

Jus, K., Kiljam, A., Kubacki, A., Rzepecki, J., Wilczak, H., & Jus, A. Studies on the effect of psychological factors on the "expectancy wave". Polish Medical Journal, 1968, 7, 1235-1241.

Karlin, L. Cognition, preparation, and sensory-evoked potentials. Psychological Bulletin, 1970, 73, 122-136.

Karlin, L., Martz, M.J., Brauth, S.E., & Mordkoff, A.M. Auditory evoked potentials, motor potentials and reaction time. *Electroencephalography and Clinical Neurophysiology*, 1971, *31*, 129-136.

Karlin, L., Martz, M.J., & Mordkoff, A.M. Motor performance and sensory-evoked potentials. *Electroencephalography and Clinical Neurophysiology*, 1970, *28*, 307-313.

Karrer, R., Fabregat, B., Czaja, J., Kohn, H., & Ptashne, R. Cortical steady potential (DC) shifts associated with response and arousal in man. *Psychophysiology*, 1971, *8*, 251.

Kirk, R.E. *Experimental design: Procedures for behavioural sciences*. Belmont, California: Brooks/Cole, 1968.

Klinke, R., Fruhstorfer, H., & Kinkezeller, P. Evoked responses as a function of external and stored information. *Electroencephalography and Clinical Neurophysiology*, 1968, *25*, 119-122.

Knott, J.R., & Irwin, D.A. Anxiety, stress, and the contingent negative variation (CNV). *Electroencephalography and Clinical Neurophysiology*, 1968, *24*, 286-287.

Knott, J.R., & Peters, J.F. Changes in CNV amplitude with progressive induction of stress as a function of sex. *Electroencephalography and Clinical Neurophysiology*, 1974, *36*, 47-51.

Kooi, K.A., Tipton, A.C., & Marshall, R.E. Polarities and field configurations of the vertex components of the human auditory response: a reinterpretation. *Electroencephalography and Clinical Neurophysiology*, 1971, *31*, 166-169.

Koppell, B.S., Wittner, W.K., & Warrich, G.L. The effect of stimulus differences, light intensity, and selective attention on the amplitude of the visual evoked potential in man. *Electroencephalography and Clinical Neurophysiology*, 1969, *26*, 619-622.

Kornhuber, H.H., & Deecke, L. Hirnpotentialanderungen bie Wilkurbewegungen und passiven Bewegungen des menschen: Bereitschaftspotential und reafferente potentiale. *Pfugers Arch*., 1965, 284, 1-7. Reported in J.J. Tecce. Contingent negative variation in man. *Psychological Bulletin*, 1972, 77, 73-108.

Lacey, J.I., & Lacey, B.C. Some autonomic-central nervous sytem interrelationships. In P. Black (Ed.), *Physiological correlates of emotion*. New York: Academic Press, 1970.

Lashley, K.S. The accuracy of movement in the absence of excitation from the moving organ. American Journal of Physiology, 1917, 43, 169-194.

Lashley, K.S. The problem of serial order in behavior. In L.A. Jeffress (Ed.), Cerebral mechanisms in behavior. New York: Wiley, 1951.

Lashley, K.S., & Ball, J. Spinal conduction and kinaesthetic sensitivity in the maze habit. Journal of Comparative Psychology, 1929, 9, 71-106.

Lashley, K.S., & McCarthy, D.A. The survival of the maze habit after cerebellar injuries. Journal of Comparative Psychology, 1926, 6, 423-434.

Lehman, D., & Fender, D.H. Component analysis of human averaged evoked potentials: dichoptic stimuli using different target structure. Electroencephalography and Clinical Neurophysiology, 1968, 24, 542-553.

Lehtonen, J.B. Functional differentiation between late components of visual evoked potentials recorded at occiput and vertex: Effect of stimulus interval and contour. Electroencephalography and Clinical Neurophysiology, 1973, 35, 75-82.

Lesèvre, N., & Renault, B. Chronotopographical study of the P300 wave and of the motor potential obtained during visual pattern stimulation in a simple reaction time task. In D.A. Otto (Ed.), Fourth international Congress on event-related slow potentials of the brain, Hendersonville, N.C., April, 1976, in press.

Locke, E.A., Cartedge, N., & Koeppel, J. Motivational effects of knowledge of results. Psychological Bulletin, 1968, 70, 474-485.

Loveless, N.E. The contingent negative variation related to preparatory set in a reaction time situation with variable foreperiod. Electroencephalography and Clinical Neurophysiology, 1973, 35, 369-374.

Loveless, N.E., & Sanford, A.J. Slow potential correlates of preparatory set. Biological Psychology, 1974, 1, 303-314.

Low, M.D., Borda, R.P., Frost, J.D., & Kellaway, P. Surface-negative slow potential shift associated with conditioning in man. Neurology, 1966, 16, 771-782.

Low, M.D., Coats, A.C., Rettig, G.M., & McSherry, J.W. Anxiety, attentiveness-alertness: A phenomenological study of the CNV. Neuropsychologica, 1967, 5, 379-384.

Low, M.D., & McSherry, J.W. Further observations of psychological factors involved in CNV genesis. Electroencephalography and Clinical Neurophysiology, 1968, 25, 203-207.

Low, M.D. & Swift, S.J. The contingent negative variation and the "resting" DC potential of the human brain: Effects of situational anxiety. Neuropsychologia, 1971, 9, 203-208.

Luria, A.R. Higher cortical functions in man. New York: Basic Books, 1966 (a).

Luria, A.R. Human brain and psychological processes. New York: Harper, 1966. (b)

Luria, A.R. The working brain, New York, Basic Books, 1973.

Luria, A.R., Pribram, K.H., & Homsakaya, E.D. An experimental analysis of the behavioural disturbance produced by left frontal arachnoidal endothellome (meningioma). Neuropsychologia, 1964, 2, 257-280.

Mackworth, J.F. The effect of true and false knowledge of results on the detection of signals in a vigilance task. Canadian Journal of Psychology, 1964, 18, 106-117.

Mandler, G. From association to structure. Psychological Review, 1962, 69, 415-427.

MacPherson, S.J., Dees, V., & Grindley, G.C. The effect of knowledge of results on learning and performance: II. Some characteristics of very simple skills. Quarterly Journal of Experimental Psychology, 1948, 1, 68-78.

MacLean, V., Ohman, A., & Lader, M. Effects of attention, activation and stimulus regularity on short-term 'habituation' of the averaged evoked response. Biological Psychology, 1975, 3, 57-69.

McAdam, D.W. Increases in CNS excitability during negative slow potentials in man. Electroencephalography and Clinical Neurophysiology, 1969, 26, 216-219.

McAdam, D.W., & Rubin, E.H., Readiness potential, vertex positive wave, contingent negative variation, and accuracy of perception. Electroencephalography and Clinical Neurophysiology, 1971, 30, 511-517.

McAdam, D.W., & Whitaker, H.A. Language production: Electrocephalographic localization in the normal human brain. Science, 1971, 172, 499-502.

McCallum, C. New waves in the brain. New Scientist, 1967, 36, 592-594.

McCallum, C. The contingent negative variation as a cortical sign of attention in man. In C.R. Evans & T.B. Mulholland (Eds.) Attention in neurophysiology. London: Butterworths, 1969.

McCallum, W.C., & Walter, W.G. The effects of attention and distraction on the contingent negative variation in normal and neurotic subjects. Electroencephalography and Clinical Neurophysiology, 1968, 25, 319-329.

Miller, G.A., Galanter, E.H., & Pribram, K.H. Plans and the structure of behavior. New York: Holt, 1960.

Milner, B.A. Evaluation of auditory function by computer techniques. International Audiology, 1969, 8, 361-370.

Naatanen, R. Selective attention and evoked potentials. Annales Academiae Scientiarum Fennicae, 1967, B151, 1-226.

Naatanen, R. Evoked potential, EEG, and slow potential correlates of selective attention. In A.F. Sanders (Ed.), Attention and performance III. Acta Psychologica, 1970, 33, 178-192.

Naatanen, R. Selective attention and evoked potentials in humans -- A critical review. Biological Psychology, 1975, 2, 237-307.

Naatanen, R., & Gaillard, A.W. The relationship between the contingent negative variation and the reaction time under prolonged experimental conditions. Biological Psychology, 1974, 1, 277-291.

Naitoh, P., Johnson, L., & Lubin, A. Modification of surface negative slow potential (CNV) in the human brain after sleep loss. Electroencephalography and Clinical Neurophysiology, 1971, 30, 17-22.

Nauta, W.J.H. Neural association of the frontal cortex. In J. Konorski, H.L. Teuber, & B. Zernicki (Eds.), Acta neurobiologiae experimentalis, The frontal granular cortex and behavior, 1972, 32. 125-140.

Neisser, U. Cognitive psychology. New York: Appleton-Century-Crofts, 1967.

Nelson, D.A., & Lassman, F.M. Effects of intersignal interval on the human auditory evoked response. *Journal of the Acoustical Society of America*, 1968, *44*, 1529-1532.

Nielson, D.W., Teas, D.C., & Idzikowski. Variation in cortical evoked responses as a function of performance criterion. *Perception and Psychophysics*, 1970, *8*, 29-32.

Osterhammel, P.A., Davis, H., Wier, C.C., & Hirsh, S.K. Adult auditory evoked vertex potentials in sleep. *Audiology*, 1973, *12*, 116-128.

Papakostopolous, D., & Fenelon, B. Spatial distribution of the contingent negative variation (CNV) and the relationship between CNV and reaction time. *Psychophysiology*, 1975, *12*, 74-78.

Paul, D.D., & Sutton, S. Evoked potential correlates of response criteria in signal detection. *Science*, 1972, *177*, 362-364.

Peters, J.F., Knott, J.R., Miller, L.H., Van Veen, W.J., & Cohen, S.I. Response variables and magnitude of the contingent negative variation, *Electroencephalography and Clinical Neurophysiology*, 1970, *29*, 608-611.

Piaget, J. *Logic psychology*. New York: Basic, 1957.

Picton, T.W., & Hillyard, S.A. Cephalic skin potentials in electroencephalography. *Electroencepalography and Clinical Neurophysiology*, 1972, *33*, 419-424.

Picton, T.W., & Hillyard, S.A. Human auditory evoked potentials II: Effects of attention. *Electroencephalography and Clinical Neurophysiology*, 1974, *36*, 191-200.

Picton, T.W., Hillyard, S.A., & Galambos, R. Evoked responses to omitted stimuli. In M. Livanov (Ed.), *Major problems of brain electrophysiology*. Academy of Sciences, U.S.S.R., 1974, 302-311 (in Russian) (a).

Picton, T.W., Hillyard, S.A., & Galambos, R. Habituation and attention in the auditory system. In W. Keidel and W. Neff (Eds.), *Handbook of sensory physiology* (Vol. 5). New York: Springer-Verlag, in press.

Picton, T.W., Hillyard, S.A., Galambos, R., & Schiff, M. Human auditory attention: A central or peripheral process? *Science*, 1971, *173*, 351-353.

Picton, T.W., Hillyard, S.A., Krausz, H.I., & Galambos, R. Human auditory evoked potentials I: Evaluation of components. Electroencephalography and Clinical Neurophysiology, 1974, 36, 179-190 (b).

Picton, T.W., & Low, M.D. The CNV and semantic content of stimuli in the experimental paradigm. Effects of feedback. Electroencephalography and Clinical Neurophysiology, 1971, 31, 451-456.

Poon, L.W., Thompson, L.W., & Marsh, G.R. Average evoked potential changes as a function of processing complexity. Psychophysiology, 1976, 13, 43-49.

Poon, L.W., Thompson, L.W., Williams, R.B., Jr., & Marsh, G.R. Changes of antero-posterior distribution of CNV and late positive component as a function of information processing demands. Psychophysiology, 1974, 11, 660-673.

Posner, M.I., Klein, R., Summers, J., & Buggie, S. On the selection of signals. Memory and Cognition, 1973, 1, 2-12.

Pribram, K.H. A review of theory in physiological psychology. Annual Review of Psychology, 1960, 11, 1-40.

Pribram, K.H. A further experimental analysis of the behavioral deficit that follows injury to the primate frontal cortex. Experimental Neurology, 1961, 3, 432-466.

Pribram, K.H. The physiology of remembering. In S. Bogoch (Ed.), The future of brain sciences. New York: Plenum Press, 1969.

Pribram, K.H. Looking to see: Some experiments in the brain mechanisms of attention in perception. Research Publication of the Association for Research in Nervous & Mental Disease, 1970, 48, 150-162.

Pribram, K.H. Languages of the brain. Englewood Cliffs, New Jersey: Prentice-Hall, 1971.

Rebert, C.S., McAdam, D.W., Knott, J.R., & Irwin, D.A. Slow potential change in human brain related to level of motivation. Journal of comparative and psysiological psychology, 1967, 63, 20-23.

Rebert, C.S., & Sperry, K.G. Subjective and response-related determinants of CNV amplitude. Psychophysiology, 1973, 10, 139-144.

Ritter, W., Simson, R., & Vaughan, H.G., Jr. Association cortex potentials and reaction time in auditory discrimination. Electroencephalography and Clinical Neurophysiology, 1972, 33, 547-555.

Ritter, W., Simson, R., & Vaughan, H.G., Jr. Topographical analysis of task related cerebral potentials. In Desmedt, J.E. (Ed.), Cerebral evoked potentials in man, in press.

Ritter, W., & Vaughan, H.G., Jr. Averaged evoked responses in vigilance and discrimination: A reassessment. Science, 1969, 164, 326-328.

Ritter, W., Vaughan, H.G., Jr., & Costa, L.D. Orienting and habituation to auditory stimuli: A study of short term changes in averaged evoked responses. Electroencephalography and Clinical Neurophysiology, 1968, 25, 550-556.

Robinson, E. The effects of degree of knowledge on results in time estimation. Psychological Record, 1963, 13, 355-360.

Roeckelein, J.E. Sex differences in time estimation. Perceptual and Motor Skills, 1972, 35, 859-862.

Roeser, R.J., & Price, L.L. Effects of habituation on the auditory evoked response. Journal of Auditory Research, 1969, 306-313.

Rogers, C.A., Jr. Feedback precision and postfeedback interval duration. Journal of Experimental Psychology, 1974, 102, 604-608.

Rohrbaugh, J.W., Donchin, E., & Eriksen, C.W. Decision making and the P300 component of the cortical evoked response. Perception and Psychophysics, 368-374.

Rose, D.E., & Ruhm, H.B. Some characteristics of the peak latency and amplitude of the acoustically evoked response. Journal of Speech and Hearing Research, 1966, 9, 412-422.

Roth, W.T. Auditory evoked responses to unpredictable stimuli. Psychophysiology, 1973, 10, 125-138.

Roth, W.T., & Kopell, B.S. P300 - An orienting reaction in the human auditory evoked response. Perceptual and Motor Skills, 1973, 36, 219-225.

Roth, W.T., Kopell, B.S., Tinklenberg, J.R., Darley, C.F., Sikora, R., & Vesecky, T.B. The contingent negative variation during a memory retrieval task. Electroencephalography and Clinical Neurophysiology, 1975, 38, 171-174.

Rothman, H., Davis, H., & Hay, I.S. Slow evoked cortical potentials and temporal features of stimulation. Electroencephalography and Clinical Neurophysiology, 1970, 29, 225-232.

Rousseau, J.C., Bostem, F., & Dongier, M. Studies on CNV: interest of recording its progressive construction during summation. Electroencephalography and Clinical Neurophysiology, 1968, 24, 95.

Rowland, V. Cortical steady potential (direct current potential) in reinforcement and learning. In E. Stellar & J.M. Sprague (Eds.), Progress in physiological psychology (Vol. 2). New York: Academic Press, 1968.

Ruchkin, D.S., & Sutton, S. Equivocation and P300 amplitude. In D. Otto (Ed.), Fourth international congress on event-related slow potentials of the brain. Hendersonville, N.C., April, 1976, in press.

Ruchkin, D.S., Sutton, S., & Tueting, P. Emitted and evoked P300 potentials and variation in stimulus probability. Psychophysiology, 1975, 12, 591-595.

Satterfield, J.H. Evoked cortical enhancement and attention in man. A study of responses to auditory and shock stimuli. Electroencephalography and Clinical Neurophysiology, 1965, 19, 470-475.

Satterthwaite, F.E. An approximate distribution of estimates of variance components. Biometrics Bulletin, 1946, 2, 110-114.

Schumsky, D.A., Grasha, A., & Seymann, R.G. Effect of rest on response decay after withdrawal of knowledge of results. Perceptual and Motor Skills, 1966, 23, 363-366.

Shagass, C. Evoked brain potentials in psychiatry. New York: Plenum Press, 1972.

Shannon, C.E., & Weaver, W. The mathematical theory of communication. Urbana: University of Illinois Press, 1949.

Sheatz, G.C., & Chapman, R.M. Task relevance and auditory evoked responses. Electroencephalography and Clinical Neurophysiology, 1969, 26, 468-475.

Simson, R., Vaughan, H.G., Jr., & Ritter, W. The scalp topography of potentials associated with missing visual or auditory stimuli. Electroencephalography and Clinical Neurophysiology, 1976, 40, 33-42.

Smith, D.B.D., Donchin, E., Cohen, L., & Starr, A. Auditory averaged evoked potentials in man during selective binaural listening. Electroencephalography and Clinical Neurophysiology, 1970, 28, 146-152.

Sokolov, E.N. Perception and the conditioned reflex. New York: Pergamon, 1963.

Sokolov, E.N. The modeling properties of the nervous system. In M. Cole & I. Maltzman (Eds.), A handbook of contemporary Soviet psychology. New York: Basic Books, 1969.

Sperling, G. The information available in brief visual presentations. Psychological Monographs, 1960, 74 (11, Whole No. 498).

Spong, P., Haider, M., & Lindsley, D.B. Selective attentiveness and cortical evoked responses to visual and auditory stimuli. Science, 1965, 148, 395-397.

Squires, K.C., Hillyard, S.A., & Lindsay, P.H. Cortical potential evoked by confirming and disconfirming feedback following an auditory discrimination. Perception and Psychophysics, 1973, 25-31(a).

Squires, K.C., Hillyard, S.A., & Lindsay, P.H. Vertex potential evoked during auditory signal detection: Relation to decision criteria. Perception and Psychophysics, 1973, 14, 265-272 (b).

Squires, K.C., Squires, N.K., & Hillyard, S.A. Vertex evoked potentials in a rating-scale detection task: Relation to signal probability. Behavioral Biology, 1975, 13, 21-34.

Squires, N.K., Squires, K.C., & Hillyard, S.A. Two varieties of long-latency positive waves evoked by unpredictable auditory stimuli in man. Electroencephalography and Clinical Neurophysiology, 1975, 38 387-401.

Squires, K.C., Wickens, C., Squires, N.K., & Donchin, E. Sequential dependencies of the waveform of the event-related potential: A preliminary report. Fourth international congress on event-related slow potentials of the brain. Hendersonville, N.C., April, 1976, in press.

Straumanis, J.J., Jr., Shagass, C., & Overton, D.A. Problems associated with application of the contingent negative variation to psychiatric research. Journal of Nervous and Mental Disease, 1969, 148, 170-179.

Stuss, D.T. Electrophysiological correlates of human concept learning. Unpublished doctoral dissertation, University of Ottawa, 1976.

Stuss, D.T., Campbell, K.B., & Picton, T.W. Electrophysiological correlates of human concept learning. Electroencephalography and Clinical Neurophysiology, (Abstract), 1976, in press.

Sutton, S., Braren, J., Zubin, J., & John, E.R. Evoked-potential correlates of stimulus uncertainty. Science, 1965, 150, 1187-1188.

Sutton, S., Tueting, P., Zubin, J., & John, E.F. Information delivery and the sensory evoked potential. Science, 1967, 155, 1436-1439.

Tecce, J.J. Contingent negative variation (CNV) and psychological processes in man. Psychological Bulletin, 1972, 77, 73-108.

Tecce, J.J., & Scheff, N.M. Attention reduction and suppressed direct-current potentials in the human brain. Science, 1969, 164, 331-333.

Thorndike, E.L. The law of effect. American Journal of Psychology, 1927, 39, 212-222.

Thorndike, E.L. Human learning. New York: Century, 1931.

Timsit, M. Koninckx, N., Dargent, J., Fontaine, O., & Dongier, M. Variations contingents négatives en psychiatrie. Electroencephalography and Clinical Neurophysiology, 1970, 28, 41-47.

Tolman, E.C. Purposive behavior in animals and men. New York: Century, 1932.

Trowbridge, M.H., & Cason, H. An experimental study of Thorndike's theory of learning. Journal of General Psychology, 1932, 7, 245-258.

Tueting, P. Correspondence on event-related potentials, cognitive events, and information processing. In D.A. Otto (Ed.), Fourth international congress on event-related slow potentials of the brain. Hendersonville, N.C., April, 1976, in press.

Tueting, P., & Sutton, S. The relationship between prestimulus negative shifts and poststimulus components of the averaged evoked potential. In S. Kornblum (ed.), Attention and performance IV. New York: Academic, 1973, 185-207.

Tueting, P.A., Sutton, S., & Zubin, J. Quantitative evoked potential correlates of the probability of events. Psychophysiology, 1971, 7, 385-394.

Vaughan, H.G., Jr. The perceptual and physiologic significance of the visual evoked responses recorded from the scalp in man. Clinical Electroretinography, Supplement to Vision Research, 1966, 203-223.

Vaughan, H.G., Jr. The relationship of brain activity to scalp recordings of event-related potentials. In E. Donchin & D.B. Lindsley (eds.), Average evoked potentials: Methods, results, and evaluations. (NASA SP-191). Washington, D.C.: Government Printing Office, 1969 (a).

Vaughan, J.G., Jr. Human brain potentials and vision. International Opthalmology Clinics, 1969, 9, 899-920 (b).

Vaughan, J.G., Jr. The analysis of scalp-recorded brain potentials. In R.F. Thompson and M.M. Patterson (Eds.), Bioelectric recording techniques, Part B: Electroencephalography and human brain potentials. New York: Academic, 1974.

Vaughan, H.G., Jr., & Hull, R.C. Unpublished computer program. Reported in H.G. Vaughan, Jr. The analysis of scalp-recorded brain potentials. In R.F. Thompson and M.M. Patterson (Eds.), Bioelectric recording techniques, Part B: Electroencephalography and human brain potentials. New York: Academic, 1974.

Vaughan, H.G., Jr., & Ritter, W. The sources of auditory evoked responses recorded from the human scalp. Electroencephalography and Clinical Neurophysiology, 1970, 28, 360-367.

Vygotsky, L.S. Thought and language. Edited and translated by E. Hanfmann & G. Vakar, Cambridge: M.I.T. Press, 1962.

Walter, W.G. The contingent negative variation: An electrocortical sign of significant association in the human brain. Science, 1964, 146, 434 (a).

Walter, W.G. The convergence and interaction of visual, auditory, and tactile responses in human nonspecific cortex. Annals of the N.Y. Academy of Sciences, 1964, 112, 60-81, (b).

Walter, W.G. Effects on anterior brain responses of an unexpected association between stimuli. Journal of Psychosomatic Research, 1965, 9, 45-49.

Walter, W.G. Expectancy waves and intention waves in the human brain and their application to the direct cerebral control of machines. Electroencephalography and Clinical Neurophysiology, 1966, 21, 616.

Walter, W.G. The contingent negative variation: An electro-cortical sign of sensori-motor reflex association in man. In E.A. Asratyan (Ed.), Progress in brain research (Vol. 22). Brain reflexes. Amsterdam: Elsevier, 1968.

Walter, W.G., Cooper, R., Aldridge, V.J., McCallum, W.C., & Winter, A.L. Contingent negative variation: An electric sign of sensorimotor association and expectancy in the human brain. Nature, 1964, 203, 380-384.

Walter, W.G., Cooper, R. Crow, H.J., McCallum, W.C., Warren, W.J., Aldridge, V.J., Storm van Leeuwen, W., & Kamp, A. Contingent negative variation and evoked responses recorded by ratio-telemetry in free-ranging subjects. Electroencephalography and Clinical Neurophysiology, 1967, 23, 197-206.

Wasman, M., Morehead, S.D., Lee, H., & Rowland, V. Interaction of electro-ocular potentials with the contingent negative variation. Psychophysiology, 1970, 7, 103-111.

Weinberg, H. The contingent negative variation: its relation to feedback and expectant attention. Neuropsychologia, 1972, 10, 299-306.

Weinberg, H. The contingent negative variation: Its clinical past and future. American Journal of EEG Technology, 1975, 15, 51-67.

Weinberg, H., & Cooper, R. The recognition index: A pattern recognition for noisy signals. Electroencephalography and Clinical Neurophysiology, 1972, 33, 608-613 (a).

Weinberg, H., & Cooper, R. The use of correlational analysis for pattern recognition. Nature, 1972, 238, 292 (b).

Weinberg, H., & Papakostopoulos, D. The frontal CNV: Its dissimilarity to CNVs recorded from other sites. Electroencephalography and Clinical Neurophysiology, 1975, 39, 21-28.

Weinberg, H., Walter, W.G., & Crow, H.J. Intracerebral events in humans related to real and imaginary stimuli. Electroencephalography and Clinical Neurophysiology, 1970, 29, 1-9.

Wilkinson, R.T., & Ashby, S.M. Selective attention, contingent negative variation, and the evoked potential. Biological Psychology, 1, 167-179.

Wilkinson, R.T., & Haines, E. Evoked potential correlates of expectancy during vigilance. Acta Psychologia, 1970, 33, 402-413.

Wilkinson, R.T., & Lee, M.V. Auditory evoked potentials and selective attention. Electroencephalography and Clinical Neurophysiology, 1972, 33, 411-418.

Wilkinson, R.T., & Morlock, H.C. Auditory evoked response and reaction time. Electroencephalography and Clinical Neurophysiology, 1967, 23, 50-56.

Wilkinson, R.T., Morlock, H.C., & Williams, H.L. Evoked cortical response during vigilance. Psychonomic Science, 1966, 4, 221-222.

Williams, H.L. & Tepas, D.I. Evoked responses to clicks and electroencephalographic stages of sleep in man. Science, 1962, 138, 685-686.

Winer, B.J. Statistical principles in experimental design. New York: McGraw-Hill, 1971.

Woody, C.D. Characteristics of an adaptive filter for the analysis of variable latency neuroelectric signals. Medical and Biological Engineering, 1967, 5, 539-553.

Worden, F.G. Attention and auditory electrophysiology. In E. Stellar, and J.M. Sprague (Eds.), Progress in physiological psychology (Vol. 1). New York: Academic Press, 1966.

Appendix A. Means and standard deviations of the frontal, central and parietal physiological data, Experiment 1-1.

COMPONENT - *AMPLITUDE PRE FEEDBACK*

Cz Location

		Total	Correct	Under	Over
NARROW WIN	M	-1.70	-2.64	-3.46	0.98
	SD	6.17	6.53	6.26	5.50
MIDDLE WIN	M	-0.35	0.35	-1.79	0.35
	SD	3.99	4.11	5.03	2.56
WIDE WIN	M	-1.01	-0.42	-1.61	-1.00
	SD	4.46	3.82	5.30	4.67
CONTROL	M	-1.52	-0.69	-2.46	-1.41
	SD	3.59	3.02	3.33	4.52

Fz Location

		Total	Correct	Under	Over
NARROW WIN	M	-4.31	-5.48	-6.24	-1.20
	SD	6.98	7.74	6.83	6.05
middle win	m	-1.70	-0.98	-3.53	-0.60
	SD	4.86	4.81	5.65	4.11
WIDE WIN	M	-2.08	-1.07	-4.13	-1.05
	SD	5.65	4.43	6.08	6.42
CONTROL	M	-2.75	-1.54	-4.09	-2.61
	SD	3.90	4.31	4.14	3.25

Pz Location

		Total	Correct	Under	Over
NARROW WIN	M	2.03	1.23	1.00	3.87
	SD	4.36	4.37	4.02	4.64
MIDDLE WIN	M	3.42	3.66	2.34	4.25
	SD	3.94	3.36	4.48	4.18
WIDE WIN	M	2.51	2.77	2.61	2.14
	SD	5.32	3.76	6.32	6.23
CONTROL	M	1.61	1.90	0.58	2.34
	SD	3.39	3.18	3.81	3.36

COMPONENT - *AMPLITUDE* N_1

		Total	Correct	Under	Over
Cz Location					
NARROW WIN	M	-1.86	-0.62	-3.53	-1.43
	SD	3.60	3.03	4.77	2.37
MIDDLE WIN	M	-1.26	-0.55	-2.17	-1.05
	SD	3.38	2.72	2.41	4.78
WIDE WIN	M	-3.80	-1.32	-4.99	-5.10
	SD	4.47	3.44	3.16	5.76
CONTROL	M	-3.81	-2.26	-3.84	-5.34
	SD	3.71	2.68	3.29	4.66
Fz Location					
NARROW WIN	M	-1.32	-0.29	-2.55	-1.14
	SD	4.14	3.67	4.82	4.10
middle win	m	-1.04	-0.26	-0.73	-2.12
	SD	3.59	4.00	3.51	3.44
WIDE WIN	M	-2.40	-0.64	-2.55	-4.02
	SD	3.09	3.60	1.65	3.01
CONTROL	M	-3.55	-2.50	-3.69	-4.47
	SD	3.18	2.49	3.20	3.80
Pz Location					
NARROW WIN	M	-2.55	-1.47	-3.44	-2.73
	SD	3.19	3.25	3.98	2.18
MIDDLE WIN	M	-1.58	-0.38	-2.68	-1.70
	SD	3.43	2.62	3.94	3.63
WIDE WIN	M	-3.81	-1.27	-3.96	-6.22
	SD	4.32	3.70	3.71	4.45
CONTROL	M	-3.02	-1.83	-3.40	-3.82
	SD	3.12	2.52	2.62	4.03

COMPONENT - *AMPLITUDE* P_2

Cz Location

		Total	Correct	Under	Over
NARROW WIN	M	17.03	20.18	14.11	16.80
	SD	7.43	8.19	6.16	7.45
MIDDLE WIN	M	16.49	16.93	16.75	15.77
	SD	7.07	7.27	7.59	7.26
WIDE WIN	M	16.61	18.03	15.01	16.78
	SD	7.65	5.72	8.19	9.34
CONTROL	M	10.71	11.72	11.16	9.24
	SD	4.89	4.22	5.06	5.61

Fz Location

		Total	Correct	Under	Over
NARROW WIN	M	12.08	13.08	11.09	12.06
	SD	5.18	5.66	5.85	4.43
middle win	m	12.74	12.06	13.00	13.17
	SD	4.17	5.08	4.11	3.68
WIDE WIN	M	12.26	12.97	13.06	10.74
	SD	5.96	3.70	7.70	6.30
CONTROL	M	7.75	8.72	7.71	6.82
	SD	4.45	4.29	4.48	4.94

Pz Location

		Total	Correct	Under	Over
NARROW WIN	M	14.58	13.47	13.94	16.35
	SD	5.65	6.01	6.08	5.15
MIDDLE WIN	M	16.46	16.96	17.00	15.41
	SD	5.38	7.01	2.81	6.02
WIDE WIN	M	15.58	15.39	15.99	15.37
	SD	4.79	4.18	5.73	4.97
CONTROL	M	10.08	11.32	8.97	9.95
	SD	4.39	4.59	4.59	4.26

COMPONENT - *AMPLITUDE* N_1-P_2

Cz Location

		Total	Correct	Under	Over
NARROW WIN	M	18.89	20.80	17.65	18.23
	SD	6.22	6.58	6.20	6.24
MIDDLE WIN	M	17.75	17.49	18.92	16.82
	SD	6.57	6.60	8.24	5.25
WIDE WIN	M	20.41	19.35	20.00	21.88
	SD	6.30	3.82	6.65	8.23
CONTROL	M	14.52	13.98	15,01	14.58
	SD	4.55	3.88	4,73	5.46

Fz Location

NARROW WIN	M	13.41	13.38	13.64	13.20
	SD	3,92	3.68	4.80	3.70
middle win	m	13.79	12.32	13.73	15.30
	SD	4.10	3.65	4.22	4.35
WIDE WIN	M	14.67	13.62	15.61	14.76
	SD	5.57	2.63	7.56	5.95
CONTROL	M	11.31	11.23	11.41	11.29
	SD	4.58	3.85	5.15	5.24

Pz Location

NARROW WIN	M	17.13	14.94	17.38	19.08
	SD	5.28	3.96	5.15	6.28
MIDDLE WIN	M	18.04	17.34	19.69	17.11
	SD	4.70	5.57	4.53	4.06
WIDE WIN	M	19.40	16.66	19.95	21.59
	SD	4.92	3.33	4.45	5.85
CONTROL	M	13.10	13.14	12.37	13.78
	SD	4.43	3.94	5.01	4.76

COMPONENT - *AMPLITUDE* N_2

Cz Location

		Total	Correct	Under	Over
NARROW WIN	M	11.27	13.44	8.86	11.52
	SD	8.57	7.76	8.80	9.58
MIDDLE WIN	M	10.79	11.59	10.38	10.40
	SD	7.07	7.94	7.19	6.97
WIDE WIN	M	9.76	12.03	7.40	9.84
	SD	8.51	7.06	8.20	10.43
CONTROL	M	4.51	6.15	4.20	3.17
	SD	5.07	6.35	4.74	4.03

Fz Location

NARROW WIN	M	5.10	6.75	3.08	5.48
	SD	6.76	7.73	6.44	6.39
middle win	m	4.64	5.07	4.22	4.63
	SD	5.77	6.17	4.94	6.83
WIDE WIN	M	5.05	6.04	4.22	4.90
	SD	5.01	4.08	5.46	5.83
CONTROL	M	1.53	3.06	0.89	0.64
	SD	4.10	4.80	4.51	2.82

Pz Location

NARROW WIN	M	10.57	10.44	9.19	12.08
	SD	6.94	6.70	8.00	6.67
MIDDLE WIN	M	12.80	14.29	13.49	10.62
	SD	6.18	6.73	4.43	7.23
WIDE WIN	M	11.79	12.32	11.76	11.29
	SD	4.76	3.75	6.19	4.63
CONTROL	M	5.82	6.82	5.19	5.45
	SD	5.10	6.22	3.91	5.46

COMPONENT - *AMPLITUDE* P_2-N_2

Cz Location

		Total	Correct	Under	Over
NARROW WIN	M	-5.75	-6.73	-5.25	-5.28
	SD	5.15	7.76	3.70	3.42
MIDDLE WIN	M	-5.69	-5.34	-6.37	-5.37
	SD	3.78	2.37	4.79	4.19
WIDE WIN	M	-6.84	-5.99	-7.60	-6.93
	SD	4.66	2.73	4.55	6.47
CONTROL	M	-6.19	-5.57	-6.95	-6.06
	SD	3.38	3.81	2.40	4.02

Fz Location

		Total	Correct	Under	Over
NARROW WIN	M	-6.97	-6.33	-8.01	-6.57
	SD	3.93	3.69	4.21	4.19
middle win	m	-8.10	-6.98	-8.77	-8.54
	SD	3.91	2.92	2.99	5.53
WIDE WIN	M	-7.20	-6.93	-8.83	-5.84
	SD	3.72	2.74	4.45	3.61
CONTROL	M	-6.22	-5.66	-6.82	-6.17
	SD	2.98	2.97	2.82	3.42

Pz Location

		Total	Correct	Under	Over
NARROW WIN	M	-4.01	-3.02	-4.74	-4.27
	SD	2.77	2.08	3.87	2.04
MIDDLE WIN	M	-3.65	-2.66	-3.51	-4.78
	SD	3.01	2,72	2.94	3.34
WIDE WIN	M	-3.78	-3.06	-4.22	-4.07
	SD	2.72	2.64	2.89	2.84
CONTROL	M	-4.25	-4.49	-3.78	-4.49
	SD	2.44	2.88	1.99	2.62

COMPONENT - *AMPLITUDE* P_3

Cz Location

		Total	Correct	Under	Over
NARROW WIN	M	21.17	23.80	18.03	21.68
	SD	7.75	7.92	6.09	8.85
MIDDLE WIN	M	21.62	18.37	24.43	22.08
	SD	8.46	8.89	6.49	9.62
WIDE WIN	M	21.70	17.22	24.94	22.93
	SD	9.47	8.16	9.56	10.01
CONTROL	M	11.77	11.43	11.99	11.90
	SD	7.15	9.41	6.94	5.57

Fz Location

NARROW WIN	M	15.35	17.18	12.82	16.06
	SD	6.30	6.27	5.32	7.15
middle win	m	17.60	13.64	19.55	19.60
	SD	8.25	6.89	7.20	9.88
WIDE WIN	M	18.40	11.94	23.20	20.04
	SD	9.48	6.03	9.37	9.71
CONTROL	M	8.75	8.10	9.15	9.01
	SD	6.11	7.46	5 78	5.74

Pz Location

NARROW WIN	M	21.85	24.05	18.52	22.97
	SD	6.81	7.62	6.06	6.15
MIDDLE WIN	M	21.70	21.05	22.28	21.77
	SD	5.30	5.97	4.07	6.26
WIDE WIN	M	21.27	16.84	24.63	22.35
	SD	7.07	7.76	5.76	5.86
CONTROL	M	10.97	10.71	10.29	11.92
	SD	5.63	7.56	5.29	4.17

COMPONENT - *AMPLITUDE* N_1- P_3

Cz Location

		Total	Correct	Under	Over
NARROW WIN	M	23.03	24.43	21.56	23.11
	SD	6.22	6.65	5.19	7.14
MIDDLE WIN	M	22.89	18.92	26.60	23.13
	SD	9.10	8.14	7.19	10.97
WIDE WIN	M	25.50	18.54	29.93	28.03
	SD	9.68	6.92	10.68	7.82
CONTROL	M	15.59	13.69	15.84	17.25
	SD	7.45	8.31	7.57	6.99

Fz Location

		Total	Correct	Under	Over
NARROW WIN	M	16.68	17.47	15.37	17.20
	SD	6.80	7.24	6.12	7.70
middle win	m	18.64	13.91	20.29	21.72
	SD	8.42	7.52	7.03	9.36
WIDE WIN	M	20.80	12.59	25.75	24.07
	SD	9.61	5.84	9.22	8.20
CONTROL	M	12.31	10.60	12.84	13.49
	SD	7.07	7.37	7.56	6.89

Pz Location

		Total	Correct	Under	Over
NARROW WIN	M	24.40	25.53	21.97	25.70
	SD	6.00	5.93	4.98	6.94
MIDDLE WIN	M	23.29	21.43	24.97	23.47
	SD	5.19	4.76	3.38	6.88
WIDE WIN	M	25.09	18.12	28.59	28.57
	SD	7.95	7.83	4.91	6.23
CONTROL	M	13.99	12.55	13.69	15.75
	SD	6.15	7.45	5.55	5.66

COMPONENT - *AMPLITUDE* N_3

Cz Location

		Total	Correct	Under	Over
NARROW WIN	M	6.13	8.88	1.79	7.71
	SD	5.18	3.82	2.78	5.72
MIDDLE WIN	M	3.95	3.53	5.12	3.20
	SD	5.83	5.50	6.18	6.40
WIDE WIN	M	6.72	6.62	7.00	6.53
	SD	5,29	3.40	5.73	6.88
CONTROL	M	-0.23	0.20	-0.33	-0.58
	SD	3.93	3.63	4.95	3.56

Fz Location

NARROW WIN	M	2.08	5.19	-2.19	3.24
	SD	4.22	2.51	2.31	3.65
middle win	m	0.22	-0.15	0.17	0.64
	SD	6.74	8.02	7.32	5.56
WIDE WIN	M	3.14	2.64	4.72	2.08
	SD	5.00	4.36	5.57	5.24
CONTROL	M	-1.30	-0.69	-0.91	-2.30
	SD	2.99	1.92	3.15	3.76

Pz Location

NARROW WIN	M	10.18	12.41	5.70	12.44
	SD	5.68	4.47	4.08	5.93
MIDDLE WIN	M	9.30	8.77	10.74	8.39
	SD	4.68	3.52	4.09	6.26
WIDE WIN	M	8.92	7.67	10.96	8.12
	SD	6.06	4.36	7.44	6.26
CONTROL	M	2.46	1.70	2.28	3.42
	SD	3.65	3.72	4.61	2.61

COMPONENT - *AMPLITUDE* P_4

Cz Location

		Total	Correct	Under	Over
NARROW WIN	M	13.33	14.09	10.82	15.08
	SD	6.52	4.57	5.26	8.92
MIDDLE WIN	M	11.90	9.57	14.29	11.83
	SD	4.63	4.92	3.28	4.76
WIDE WIN	M	12.99	11.16	14.61	13.20
	SD	4.87	2.66	6.70	4.38
CONTROL	M	5.39	4.87	6.60	4.69
	SD	4.20	4.22	3.79	4.83

Fz Location

NARROW WIN	M	7.78	8.27	5.25	9.82
	SD	4.82	4.17	3.96	5.57
middle win	m	8.25	6.48	8.99	9.28
	SD	4.61	4.51	4.67	4.71
WIDE WIN	M	9.45	8.01	12.06	8.27
	SD	5.17	2.32	6.84	4.90
CONTROL	M	3.05	2.05	4.22	2.88
	SD	4.29	2.05	3.99	6.14

Pz Location

NARROW WIN	M	15.84	18.03	12.12	17.36
	SD	6.35	4.76	5.19	7.69
MIDDLE WIN	M	15.78	13.33	17.69	16.33
	SD	3.86	2.92	4.24	3.33
WIDE WIN	M	14.49	11.43	17.34	14.70
	SD	6.40	4.78	8.44	4.52
CONTROL	M	7.24	6.51	7.56	7.67
	SD	3.85	3.95	4.33	3.67

COMPONENT - *AMPLITUDE* N_1-P_4

		Total	Correct	Under	Over
Cz Location					
NARROW WIN	M	15.20	14.72	14.36	16.51
	SD	6.87	5.13	8.06	7.79
MIDDLE WIN	M	13.16	10.14	16.46	12.88
	SD	5.70	3.77	4.92	6.73
WIDE WIN	M	16.79	12.48	19.60	18.30
	SD	6.08	4.66	7.24	3.81
CONTROL	M	9.21	7.13	10.44	10.04
	SD	4.64	4.11	4.43	5.16
Fz Location					
NARROW WIN	M	9.11	8.57	7.80	10.96
	SD	6.61	6.63	6.74	6.93
middle win	m	9.30	6.75	9.73	11.41
	SD	4.93	3.81	4.16	5.93
WIDE WIN	M	11.85	8.65	14.61	12.30
	SD	5.73	4.46	6.75	4.68
CONTROL	M	6.61	4.56	7.92	7.35
	SD	4.89	3.45	4.84	6.00
Pz Location					
NARROW WIN	M	18.39	19.51	15.57	20.09
	SD	6.47	4.20	6.03	8.35
MIDDLE WIN	M	17.37	13.71	20.38	18.03
	SD	4.92	2.75	5.21	4.32
WIDE WIN	M	18.31	12.70	21.30	20.92
	SD	7.55	7.58	6.52	5.79
CONTROL	M	10.27	8.34	10.96	11.50
	SD	3.90	3.96	4.21	3.16

COMPONENT - *AMPLITUDE POST FEEDBACK*

Cz Location

		Total	Correct	Under	Over
NARROW WIN	M	3.09	4.05	-0.33	5.57
	SD	5.57	4.87	4.03	6.38
MIDDLE WIN	M	3.52	2.55	6.13	1.87
	SD	3.89	3.35	3.89	3.36
WIDE WIN	M	2.76	3.96	1.45	2.88
	SD	4.34	3.43	5.52	3.99
CONTROL	M	-2.29	-2.84	-1.70	-2.32
	SD	3.57	3.04	5.04	2.54

Fz Location

NARROW WIN	M	-0.02	-0.17	-2.41	2.52
	SD	4.44	3.32	4.17	4.74
middle win	m	1.84	1.34	2.86	1.32
	SD	5.86	5.84	6.10	6.31
WIDE WIN	M	0.88	2.43	1.07	-0.85
	SD	3.62	3.42	2.95	4.06
CONTROL	M	-1.46	-1.23	0.13	-3.28
	SD	4.00	4.66	3.63	3.31

Pz Location

NARROW WIN	M	3.58	5.61	0.38	4.76
	SD	4.95	3.70	4.83	5.04
MIDDLE WIN	M	4.11	3.82	5.66	2.84
	SD	3.90	3.11	3.59	4.77
WIDE WIN	M	2.52	4.56	1.49	1.52
	SD	5.38	6.14	4.91	5.10
CONTROL	M	-0.91	-1.18	-0.94	-0.60
	SD	4.54	3.62	6.30	3.84

Appendix B. Means and standard deviations of the frontal, central, and parietal physiological data, Experiment 2-1.

COMPONENT - *AMPLITUDE PRE FEEDBACK*

		Total	Correct	Under	Over
Cz Location					
NEG and POS	M	-1.51	-1.05	-1.70	-1.79
	SD	4.79	4.29	4.77	5.82
NEG INCEN	M	-1.64	-0.71	-2.68	-1.52
	SD	4.39	3.86	5.66	3.77
POS INCEN	M	-1.96	-1.38	-2.88	-1.61
	SD	5.60	6.00	5.70	5.76
NO INCEN	M	-1.65	-1.02	-1.16	-2.77
	SD	4.02	3.18	4.94	4.05
Fz Location					
NEG and POS	M	0.33	0.79	0.96	-0.69
	SD	4.48	3.92	4.98	4.83
NEG INCEN	M	0.70	2.84	-0.78	0.04
	SD	4.31	3.47	4.90	4.07
POS INCEN	M	0.14	1.09	-1.11	0.44
	SD	5.77	5.98	6.30	5.58
NO INCEN	M	0.14	-0.40	1.63	-0.80
	SD	3.53	2.19	4.89	2.91
Pz Location					
NEG and POS	M	-3.95	-3.66	-4.22	-3.96
	SD	4.25	3.83	3.76	5.52
NEG INCEN	M	-4.99	-3.80	-5.81	-5.34
	SD	3.76	3.31	4.59	3.45
POS INCEN	M	-4.81	-3.71	-7.11	-3.62
	SD	4.64	4.25	5.43	3.75
NO INCEN	M	-4.23	-3.96	-4.29	-4.45
	SD	3.80	3.27	4.47	4.07

COMPONENT - *AMPLITUDE* N_1

Cz Location

		Total	Correct	Under	Over
NEG and POS	M	-0.85	-0.00	-0.13	-2.41
	SD	3.69	3.68	4.04	3.27
NEG INCEN	M	-2.85	-1.76	-2.68	-4.11
	SD	3.91	3.88	3.54	4.41
POS INCEN	M	-1.57	-1.74	0.33	-3.31
	SD	3.45	2.90	4.32	2.09
NO INCEN	M	-1.84	-1.43	-2.14	-1.94
	SD	3.58	3.37	3.64	4.16

Fz Location

NEG and POS	M	0.00	1.20	-0.06	-0.98
	SD	3.38	2.21	3.20	4.35
NEG INCEN	M	-2.30	-1.63	-1.83	-3.44
	SD	3.26	2.69	3.00	4.04
POS INCEN	M	-2.16	-2.23	-1.54	-2.70
	SD	3.19	2.27	3.97	3.44
NO INCEN	M	-1.28	-0.08	-1.79	-1.96
	SD	4.04	3.61	4.21	4.53

Pz Location

NEG and POS	M	-1.50	0.09	-1.14	-3.46
	SD	3.84	2.62	4.01	4.26
NEG INCEN	M	-2.05	-0.67	-3.44	-2.05
	SD	4.60	3.90	4.76	5.23
POS INCEN	M	-2.26	-1.61	-1.11	-4.07
	SD	3.78	3.08	4.21	3.76
NO INCEN	M	-1.70	-1.25	-2.37	-1.49
	SD	3.20	3.80	3.06	3.00

COMPONENT - *AMPLITUDE* P_2

Cz Location		Total	Correct	Under	Over
NEG and POS	M	18.15	20.58	18.30	15.57
	SD	6.20	7.55	5.36	5.11
NEG INCEN	M	15.92	17.16	17.29	13.31
	SD	5.89	6.27	3.50	7.13
POS INCEN	M	16.46	18.28	17.96	13.15
	SD	5.96	5.70	5.32	6.10
NO INCEN	M	16.89	18.12	17.00	15.55
	SD	6.14	7.41	5.07	6.27

Fz Location					
NEG and POS	M	13.50	16.46	12.91	11.50
	SD	4.62	5.41	3.66	3.84
NEG INCEN	M	11.61	12.10	13.02	9.71
	SD	4.46	5.45	2.34	4.87
POS INCEN	M	12.78	14.27	13.44	10.62
	SD	4.74	5.30	3.99	4.62
NO INCEN	M	12.49	13.69	12.61	11.16
	SD	5.14	5.58	5.58	4.57

Pz Location					
NEG and POS	M	16.16	17.69	15.12	15.66
	SD	5.29	5.66	4.05	6.26
NEG INCEN	M	16.34	16.71	16.80	15.52
	SD	5.84	6.82	3.67	7.13
POS INCEN	M	15.92	16.51	17.52	13.73
	SD	4.87	3.84	4.66	5.71
NO INCEN	M	15.90	15.99	15.86	15.84
	SD	5.04	6.70	4.03	4.73

COMPONENT - *AMPLITUDE* N_1-P_2

Cz Location

		Total	Correct	Under	Over
NEG and POS	M	19.00	20.58	18.43	17.98
	SD	3.85	4.34	3.02	4.05
NEG INCEN	M	18.78	18.92	19.98	17.43
	SD	6.03	3.05	4.94	9.05
POS INCEN	M	18.04	20.02	17.63	16.46
	SD	5.92	5.00	7.58	5.03
NO INCEN	M	18.73	19.55	19.15	17.49
	SD	5.16	5.55	2.63	6.86

Fz Location

		Total	Correct	Under	Over
NEG and POS	M	13.50	15.26	12.97	12.48
	SD	3.93	3.48	2.84	5.06
NEG INCEN	M	13.91	13.73	14.85	13.15
	SD	4.77	2.95	3.53	7.20
POS INCEN	M	14.94	16.51	14.99	13.33
	SD	4.88	4.95	5.94	3.56
NO INCEN	M	13.77	13.78	14.40	13.13
	SD	4.57	4.29	3.33	6.18

Pz Location

		Total	Correct	Under	Over
NEG and POS	M	17.66	17.60	16.26	19.13
	SD	4.05	3.86	2.56	5.27
NEG INCEN	M	18.40	17.38	20.24	13.58
	SD	5.69	5.70	5.20	6.41
POS INCEN	M	18.19	18.12	18.63	17.81
	SD	5.36	4.30	6.60	5.65
NO INCEN	M	17.60	17.25	18.23	17.34
	SD	3.61	4.41	1.62	4.73

COMPONENT - *AMPLITUDE* N_2

Cz Location

		Total	Correct	Under	Over
NEG and POS	M	12.72	15.61	12.84	9.71
	SD	7.35	7.55	5.56	8.36
NEG INCEN	M	9.77	12.46	12.39	4.45
	SD	6.32	5.96	4.25	5.40
POS INCEN	M	11.00	14.34	10.89	7.78
	SD	6.25	7.35	4.24	5.65
NO INCEN	M	11.52	13.06	11.45	10.04
	SD	6.10	7.17	5.97	5.49

Fz Location

		Total	Correct	Under	Over
NEG and POS	M	7.16	11.20	6.28	4.52
	SD	5.75	4.22	4.14	6.80
NEG INCEN	M	4.73	6.66	6.60	0.94
	SD	5.36	5.53	4.41	4.42
POS INCEN	M	5.36	7.92	4.85	3.31
	SD	5.36	6.11	4.72	4.73
NO INCEN	M	5.58	8.34	4.63	3.78
	SD	6.62	6.60	6.09	7.06

Pz Location

		Total	Correct	Under	Over
NEG and POS	M	11.90	14.32	10.20	11.18
	SD	6.44	5.95	3.91	8.66
NEG INCEN	M	11.12	13.44	12.19	7.71
	SD	6.09	6.95	3.81	6.18
POS INCEN	M	11.25	14.20	11.23	8.32
	SD	5.76	5.43	4.40	6.36
NO INCEN	M	11.76	12.64	11.83	10.82
	SD	5.77	6.28	6.06	5.60

COMPONENT - *AMPLITUDE* P_2-N_2

Cz Location

		Total	Correct	Under	Over
NEG and POS	M	-5.43	-4.96	-5.45	-5.86
	SD	3.63	2.97	3.32	4.80
NEG INCEN	M	-6.15	-4.69	-4.90	-8.86
	SD	4.95	2.88	1.95	7.47
POS INCEN	M	-5.45	-3.93	-7.07	-5.37
	SD	4.65	3.15	5.59	4.92
NO INCEN	M	-5.37	-5.05	-5.54	-5.50
	SD	3.39	3.18	3.86	3.54
Fz Location					
NEG and POS	M	-6.33	-5.26	-6.62	-6.98
	SD	3.16	2.76	2.03	4.36
NEG INCEN	M	-6.87	-5.43	-6.42	-8.77
	SD	4.66	2.71	3.14	6.88
POS INCEN	M	-7.42	-6.35	-8.59	-7.31
	SD	4.24	2.55	6.20	3.35
NO INCEN	M	-6.90	-5.34	-7.98	-7.38
	SD	4.01	2.17	3.94	5.32
Pz Location					
NEG and POS	M	-4.25	-3.37	-4.92	-4.47
	SD	2.60	1.64	2.57	3.39
NEG INCEN	M	-5.22	-3.26	-4.60	-7.80
	SD	5.12	4.12	2.14	7.22
POS INCEN	M	-4.66	-2.30	-6.38	-5.41
	SD	4.90	2.45	6.26	4.87
NO INCEN	M	-4.13	-3.35	-4.02	-5.01
	SD	2.87	2.43	3.39	2.86

COMPONENT - *AMPLITUDE* P_3

		Total	Correct	Under	Over
Cz Location					
NEG and POS	M	25.52	24.47	26.71	25.37
	SD	6.83	7.11	4.54	8.90
NEG INCEN	M	22.24	20.36	24.50	21.88
	SD	8.44	6.24	5.32	12.52
POS INCEN	M	24.17	23.40	24.92	24.18
	SD	6.63	6.94	5.98	7.69
NO INCEN	M	23.44	22.86	25.12	22.33
	SD	7.88	5.15	9.87	8.66
Fz Location					
NEG and POS	M	19.55	18.28	21.41	18.79
	SD	6.08	6.67	3.99	7.49
NEG INCEN	M	16.29	14.45	18.21	16.22
	SD	7.57	5.33	5.82	10.86
POS INCEN	M	18.72	18.01	20.56	17.58
	SD	6.37	7.56	6.08	5.77
NO INCEN	M	17.36	16.66	18.90	16.51
	SD	7.47	4.80	9.24	8.42
Pz Location					
NEG and POS	M	24.35	25.26	23.96	23.85
	SD	4.53	5.15	3.40	5.30
NEG INCEN	M	22.44	22.68	22.35	22.28
	SD	6.06	5.55	3.14	8.93
POS INCEN	M	23.71	24.63	24.94	21.56
	SD	5.44	4.88	4.68	6.60
NO INCEN	M	22.77	23.74	22.77	21.79
	SD	6.58	6.78	7.09	6.62

COMPONENT - *AMPLITUDE* N_1-P_3

Cz Location

		Total	Correct	Under	Over
NEG and POS	M	26.37	24.47	26.83	27.79
	SD	6.14	7.28	3.91	6.99
NEG INCEN	M	25.10	22.12	27.18	26.00
	SD	7.19	5.49	4.74	10.07
POS INCEN	M	25.74	25.14	24.59	27.49
	SD	7.86	7.89	8.94	7.45
NO INCEN	M	25.28	24.29	27.27	24.27
	SD	6.48	4.13	8.99	5.79

Fz Location

		Total	Correct	Under	Over
NEG and POS	M	19.55	17.08	21.48	19.77
	SD	5.79	6.58	2.71	7.11
NEG INCEN	M	18.60	16.08	20.04	19.66
	SD	6.65	5.17	5.16	9.01
POS INCEN	M	20.88	20.24	22.10	20.29
	SD	6.79	8.36	7.25	5.17
NO INCEN	M	18.64	16.75	20.69	18.48
	SD	5.66	5.51	6.93	5.30

Pz Location

		Total	Correct	Under	Over
NEG and POS	M	25.86	25.17	25.10	27.32
	SD	4.19	4.16	3.01	5.26
NEG INCEN	M	24.50	23,35	25.79	24.34
	SD	5.98	3.65	4.09	9.16
POS INCEN	M	25.98	26.24	26.06	25.64
	SD	6.71	6.60	6.77	7.63
NO INCEN	M	24.47	24.99	25.14	23.29
	SD	5.03	3.82	6.04	5.44

COMPONENT - *AMPLITUDE* N_3

		Total	Correct	Under	Over
Cz Location					
NEG and POS	M	7.92	10.71	7.20	5.84
	SD	5.02	4.73	5.12	4.46
NEG INCEN	M	5.66	6.89	6.28	3.82
	SD	6.54	3.00	7.80	8.04
POS INCEN	M	7.03	7.78	6.66	6.64
	SD	5.76	5.68	5.35	6.88
NO INCEN	M	8.19	7.20	4.96	12.41
	SD	15.15	5.62	5.37	25.70
Fz Location					
NEG and POS	M	1.64	1.66	1.94	1.32
	SD	4.23	4.08	5.25	3.77
NEG INCEN	M	0.89	1.94	0.73	0.00
	SD	5.86	5.10	6.63	6.38
POS INCEN	M	2.24	2.23	1.83	2.66
	SD	4.28	5.18	3.79	4.30
NO INCEN	M	2.23	4.18	2.23	0.26
	SD	5.29	5.41	4.87	5.49
Pz Location					
NEG and POS	M	11.12	12.64	10.20	10.53
	SD	3.96	3.35	3.42	4.96
NEG INCEN	M	10.25	11.05	9.24	10.47
	SD	5.48	3.29	4.26	8.23
POS INCEN	M	10.58	9.71	11.63	10.40
	SD	5.45	4.13	5.85	6.65
NO INCEN	M	9.60	11.23	8.79	8.79
	SD	3.75	4.31	3.76	2.99

COMPONENT - *AMPLITUDE P_4*

Cz Location

		Total	Correct	Under	Over
NEG and POS	M	15.74	15.46	15.90	15.86
	SD	5.12	5.46	5.67	4.90
NEG INCEN	M	13.17	12.32	14.27	12.91
	SD	3.90	2.15	5.30	3.86
POS INCEN	M	14.05	13.26	14.47	14.40
	SD	5.91	6.79	5.26	6.31
NO INCEN	M	12.77	14.00	11.05	13.26
	SD	4.68	4.09	5.94	3.81

Fz Location

		Total	Correct	Under	Over
NEG and POS	M	8.26	6.00	9.33	9.17
	SD	4.84	4.12	4.29	5.77
NEG INCEN	M	8.00	7.49	9.19	7.31
	SD	3.80	3.27	4.91	3.20
POS INCEN	M	8.44	6.84	9.95	8.52
	SD	5.69	5.98	5.62	5.78
NO INCEN	M	8.74	10.40	8.10	7.71
	SD	4.75	4.81	4.36	5.21

Pz Location

		Total	Correct	Under	Over
NEG and POS	M	17.90	17.85	17.76	18.10
	SD	4.46	3.92	4.65	5.31
NEG INCEN	M	16.49	15.57	16.02	17.90
	SD	4.73	3.98	4.59	5.76
POS INCEN	M	16.90	15.26	17.90	17.54
	SD	4.88	4.23	5.41	5.14
NO INCEN	M	14.73	15.55	12.73	15.90
	SD	4.08	4.19	4.36	3.34

COMPONENT - *AMPLITUDE* N_1-P_4

Cz Location		Total	Correct	Under	Over
NEG and POS	M	16.59	15.46	16.04	18.28
	SD	6.16	6.34	6.90	5.66
NEG INCEN	M	16.06	14.09	16.96	17.02
	SD	6.09	4.35	7.21	6.68
POS INCEN	M	15.62	15.01	14.14	17.72
	SD	7.03	8.21	5.91	7.21
NO INCEN	M	14.61	15.43	13.20	15.21
	SD	5.70	6.24	7.00	3.93
Fz Location					
NEG and POS	M	8.26	4.80	9.39	10.15
	SD	5.92	3.91	5.34	7.13
NEG INCEN	M	10.30	9.12	11.03	10.76
	SD	5.00	4.34	5.11	5.90
POS INCEN	M	10.60	9.08	11.50	11.23
	SD	7.33	7.26	7.75	7.72
NO INCEN	M	10.02	10.49	9.89	9.68
	SD	5.03	5.94	5.18	4.53
Pz Location					
NEG and POS	M	19.41	17.76	18.90	21.56
	SD	5.58	3.40	6.88	5.90
NEG INCEN	M	18.55	16.24	19.46	19.95
	SD	7.50	6.35	8.53	7.92
POS INCEN	M	19.16	16.87	19.01	21.61
	SD	7.67	6.54	8.97	7.58
NO INCEN	M	16.43	16.80	15.10	17.40
	SD	5.56	6.11	6.62	4.12

COMPONENT - *AMPLITUDE POST FEEDBACK*

Cz Location		Total	Correct	Under	Over
NEG and POS	M	4.85	5.10	6.08	3.37
	SD	5.13	4.96	4.57	6.07
NEG INCEN	M	3.51	3.15	4.67	2.70
	SD	5.22	4.37	6.41	5.19
POS INCEN	M	4.19	1.94	5.54	5.10
	SD	6.38	6.14	4.96	7.91
NO INCEN	M	3.34	3.55	2.57	3.91
	SD	5.52	4.62	6.17	6.30
Fz Location					
NEG and POS	M	2.26	1.17	3.31	2.17
	SD	4.39	5.19	3.64	4.66
NEG INCEN	M	1.55	1.43	2.14	1.07
	SD	5.58	5.84	5.90	5.73
POS INCEN	M	2.88	1.41	3.22	4.02
	SD	5.94	6.20	5.82	6.28
NO INCEN	M	1.77	2.21	1.27	1.83
	SD	5.91	4.10	7.57	6.33
Pz Location					
NEG and POS	M	5.27	6.26	4.87	4.67
	SD	4.76	4.15	4.40	5.99
NEG INCEN	M	4.16	4.43	4.76	3.31
	SD	4.35	4.11	4.50	4.87
POS INCEN	M	4.45	3.55	5.63	4.16
	SD	5.34	5.10	5.71	5.71
NO INCEN	M	3.85	4.60	3.20	3.75
	SD	4.54	3.24	4.50	5.99

Appendix C. Means and standard deviations of the frontal, central, and parietal physiological data, Experiment 2-2.

COMPONENT - *AMPLITUDE PRE FEEDBACK*

Condition = Equal Value

			Fz	Cz	Pz
Correct	+10	M	-0.17	-3.04	-5.16
		SD	4.25	4.77	4.57
Incorrect	-10	M	-1.34	-3.31	-5.34
		SD	3.97	4.06	4.59
Incorrect	-10	M	0.26	-3.04	-5.88
		SD	4.70	5.35	5.02

Condition = Unequal Value

			Fz	Cz	Pz
Correct	+10	M	-0.48	-3.31	-5.26
		SD	4.38	4.74	3.87
Incorrect	±0	M	-1.91	-4.02	-6.80
		SD	4.01	3.03	4.75
Incorrect	-20	M	0.09	-2.79	-3.58
		SD	3.01	5.15	3.00

COMPONENT - *AMPLITUDE* N_1

Condition = Equal Value

			Fz	Cz	Pz
Correct	+10	M	-0.62	1.09	0.67
		SD	2.38	3.76	4.57
Incorrect	-10	M	-1.49	-0.78	-0.38
		SD	5.17	5.18	4.95
Incorrect	-10	M	-2.05	-1.87	-1.43
		SD	2.69	3.67	3.88

Condition = Unequal Value

			Fz	Cz	Pz
Correct	+10	M	-0.20	-0.17	-0.46
		SD	3.26	3.27	3.03
Incorrect	±0	M	-0.53	-1.38	-1.63
		SD	2.85	5.03	4.14
Incorrect	-20	M	-2.95	-1.52	-3.88
		SD	3.30	4.43	5.04

COMPONENT - *AMPLITUDE* P_2

Condition = Equal Value

			Fz	Cz	Pz
Correct	+10	M	13.55	19.84	18.23
		SD	4.61	7.32	7.65
Incorrect	-10	M	12.97	18.99	18.54
		SD	4.78	5.01	3.95
Incorrect	-10	M	10.60	16.24	15.59
		SD	5.87	7.98	7.12

Condition = Unequal Value

			Fz	Cz	Pz
Correct	+10	M	13.50	17.13	15.24
		SD	4.00	3.58	4.36
Incorrect	±0	M	10.05	14.32	13.14
		SD	5.22	6.77	4.56
Incorrect	-20	M	8.41	15.23	13.52
		SD	6.41	4.68	5.46

COMPONENT - *AMPLITUDE* N_1-P_2

Condition = Equal Value

			Fz	Cz	Pz
Correct	+10	M	14.18	18.75	17.56
		SD	4.96	5.18	5.55
Incorrect	-10	M	14.47	19.77	18.92
		SD	3.38	2.95	2.36
Incorrect	-10	M	12.66	18.12	17.02
		SD	4.82	5.53	5.78

Condition = Unequal Value

			Fz	Cz	Pz
Correct	+10	M	13.70	17.31	15.70
		SD	3.54	4.52	3.85
Incorrect	±0	M	10.58	15.70	14.78
		SD	4.30	4.91	4.43
Incorrect	-20	M	11.36	16.75	17.41
		SD	3.72	4.83	4.84

COMPONENT - *AMPLITUDE* N_2

Condition = Equal Value

			Fz	Cz	Pz
Correct	+10	M	8.61	15.81	15.68
		SD	5.46	7.68	7.30
Incorrect	-10	M	5.63	12.46	11.90
		SD	7.51	7.62	6.32
Incorrect	-10	M	2.86	10.06	10.53
		SD	6.21	7.35	6.74

Condition = Unequal Value

			Fz	Cz	Pz
Correct	+10	M	6.36	12.66	13.98
		SD	5.25	4.08	4.95
Incorrect	±0	M	6.70	9.37	9.28
		SD	4.85	8.75	6.45
Incorrect	-20	M	5.66	9.91	9.07
		SD	5.18	3.62	6.34

COMPONENT - *AMPLITUDE* P_2-N_2

Condition = Equal Value

			Fz	Cz	Pz
Correct	+10	M	-4.94	-4.02	-2.55
		SD	4.06	2.77	2.84
Incorrect	-10	M	-7.33	-6.53	-6.64
		SD	4.38	3.07	3.21
Incorrect	-10	M	-7.74	-6.17	-5.05
		SD	4.05	4.16	3.79

Condition = Unequal Value

			Fz	Cz	Pz
Correct	+10	M	-7.13	-4.94	-3.86
		SD	2.28	4.37	3.30
Incorrect	±0	M	-3.35	-5.32	-1.25
		SD	4.41	3.28	0.78
Incorrect	-20	M	-2.74	-5.32	-4.49
		SD	1.40	3.28	3.13

COMPONENT - *AMPLITUDE* P_3

Condition = Equal Value

			Fz	Cz	Pz
Correct	+10	M	13.67	22.46	23.58
		SD	4.11	6.12	5.36
Incorrect	-10	M	17.67	23.31	23.07
		SD	8.23	8.50	8.16
Incorrect	-10	M	21.82	23.76	22.46
		SD	9.38	8.80	8.29

Condition = Unequal Value

			Fz	Cz	Pz
Correct	+10	M	13.40	21.99	23,86
		SD	4.00	4.65	4.08
Incorrect	±0	M	17.29	26.45	23.52
		SD	2.67	8.89	7.19
Incorrect	-20	M	19.84	23.18	21.99
		SD	5.51	7.08	8.01

COMPONENT - AMPLITUDE N_1-P_3

Condition = Equal Value

			Fz	Cz	Pz
Correct	+10	M	14.30	21.37	22.91
		SD	4.17	4.29	3.67
Incorrect	-10	M	19.17	24.10	23.45
		SD	5.70	4.29	6.36
Incorrect	-10	M	18.68	25.64	23.89
		SD	5.87	7.15	6.97

Condition = Unequal Value

			Fz	Cz	Pz
Correct	+10	M	13.60	22.17	24.31
		SD	2.74	5.02	4.78
Incorrect	±0	M	17.82	27.83	25.16
		SD	1.54	9.00	7.03
Incorrect	-20	M	22.79	24.70	25.88
		SD	5.24	4.48	5.77

COMPONENT - *AMPLITUDE* N_3

Condition = Equal Value

			Fz	Cz	Pz
Correct	+10	M	-0.36	8.03	11.99
		SD	5.87	4.59	3.17
Incorrect	-10	M	-0.96	3.65	8.32
		SD	7.15	6.26	4.88
Incorrect	-10	M	1.14	5.62	9.42
		SD	5.04	6.32	8.54

Condition = Unequal Value

			Fz	Cz	Pz
Correct	+10	M	2.81	8.68	11.89
		SD	5.90	3.97	3.02
Incorrect	±0	M	1.71	5.99	10.15
		SD	4.41	4.02	5.57
Incorrect	-20	M	0.47	5.97	9.87
		SD	3.88	5.26	2.53

COMPONENT - *AMPLITUDE* P_4

Condition = Equal Value

			Fz	Cz	Pz
Correct	+10	M	4.81	12.51	16.02
		SD	4.96	3.33	3.25
Incorrect	-10	M	9.24	14.45	16.27
		SD	5.87	5.30	5.41
Incorrect	-10	M	8.18	14.90	16.80
		SD	7.15	7.43	7.35

Condition = Unequal Value

			Fz	Cz	Pz
Correct	+10	M	7.82	14.03	18.95
		SD	6.85	3.95	2.96
Incorrect	±0	M	8.69	15.04	17.69
		SD	4.60	3.84	5.81
Incorrect	-20	M	8.29	14.92	17.87
		SD	4.20	4.47	2.87

COMPONENT - *AMPLITUDE* N_1-P_4

Condition = Equal Value

			Fz	Cz	Pz
Correct	+10	M	5.43	11.41	15.35
		SD	6.14	6.29	5.38
Incorrect	-10	M	10.74	15.23	16.65
		SD	5.78	5.11	5.58
Incorrect	-10	M	10.25	16.78	18.26
		SD	6.43	7.57	7.09

Condition = Unequal Value

			Fz	Cz	Pz
Correct	+10	M	8.03	14.21	19.41
		SD	5.20	5.67	4.70
Incorrect	±0	M	9.23	16.42	19.33
		SD	5.70	7.37	6.57
Incorrect	-20	M	11.25	16.45	21.76
		SD	4.27	5.70	5.10

COMPONENT - *AMPLITUDE POST FEEDBACK*

Condition = Equal Value

			Fz	Cz	Pz
Correct	+10	M	0.96	4.61	5.48
		SD	7.00	5.20	3.30
Incorrect	-10	M	3.40	4.68	4.99
		SD	4.58	3.48	2.63
Incorrect	-10	M	2.42	4.97	4.27
		SD	6.56	6.57	5.27

Condition = Unequal Value

			Fz	Cz	Pz
Correct	+10	M	2.91	5.84	6.88
		SD	7.20	5.06	5.44
Incorrect	±0	M	2,71	4.90	2.02
		SD	3.42	4.14	4.77
Incorrect	-20	M	5.73	4.50	4.53
		SD	4.00	5.14	3.36

Appendix D. Means and standard deviations of the frontal, central, and parietal physiological data, Experiment 3-1.

COMPONENT - *AMPLITUDE PRE FEEDBACK*

Cz Location

		Total	Correct	Under	Over
QUAN	M	3.37	4.29	4.05	1.79
	SD	5.31	3.99	5.66	6.35
QUAL-HI	M	3.19	4.27	3.31	1.99
	SD	5.28	5.38	4.89	5.98
CONT-HI	M	2.63	1.63	2.41	3.84
	SD	3.43	3.00	3.60	3.72

Fz Location

QUAN	M	0.32	1.00	1.18	-1.20
	SD	4.21	3.74	4.17	4.73
QUAL-HI	M	0.36	1.38	0.58	-0.87
	SD	4.36	4.53	4.47	4.36
CONT-HI	M	1.52	0.31	1.67	2.57
	SD	4.13	3.38	4.91	4.19

Pz Location

QUAN	M	6.65	6.69	7.69	5.57
	SD	4.27	2.89	5.95	3.68
QUAL-HI	M	5.95	8.23	5.77	3.87
	SD	3.93	2.98	3.40	4.41
CONT-HI	M	3.03	1.07	3.89	4.13
	SD	3.43	3.49	3.07	3.23

COMPONENT - *AMPLITUDE* N_1

Cz Location

		Total	Correct	Under	Over
QUAN	M	-1.13	-0.26	-0.69	-2.43
	SD	3.70	3.98	4.54	2.35
QUAL-HI	M	-0.94	0.67	-1.99	-1.52
	SD	4.14	5.17	4.49	2.21
CONT-HI	M	-2.59	-2.08	-3.31	-2.39
	SD	4.60	7.12	3.60	2.24

Fz Location

		Total	Correct	Under	Over
QUAN	M	-1.46	-0.87	-0.89	-2.61
	SD	4.13	4.55	3.46	4.59
QUAL-HI	M	-1.26	0.20	-2.34	-1.63
	SD	4.21	5.50	3.95	2.93
CONT-HI	M	-2.49	-1.81	-2.86	-2.81
	SD	3.07	4.82	2.28	1.34

Pz Location

		Total	Correct	Under	Over
QUAN	M	-1.58	-0.60	-2.41	-1.72
	SD	3.84	3.21	5.20	3.06
QUAL-HI	M	-1.20	0.00	-1.47	-2.12
	SD	4.18	4.90	4.50	3.24
CONT-HI	M	-2.54	-2.23	-2.88	-2.50
	SD	4.22	5.41	4.26	3.29

COMPONENT - *AMPLITUDE* P_2

Cz Location

		Total	Correct	Under	Over
QUAN	M	19.13	22.26	19.82	15.30
	SD	9.52	11.35	8.40	8.36
QUAL-HI	M	19.04	20.96	18.45	17.73
	SD	7.95	10.50	6.76	6.73
CONT-HI	M	11.03	13.15	10.06	9.89
	SD	5.53	8.02	3.70	3.85

Fz Location

		Total	Correct	Under	Over
QUAN	M	12.98	15.68	14.14	9.12
	SD	6.86	7.91	7.17	3.72
QUAL-HI	M	13.26	17.54	11.61	10.62
	SD	7.21	8.03	5.87	6.34
CONT-HI	M	8.78	10.85	7.78	7.71
	SD	4.04	5.45	2.11	3.48

Pz Location

		Total	Correct	Under	Over
QUAN	M	18.00	19.55	20.00	14.45
	SD	7.85	10.12	6.33	6.19
QUAL-HI	M	18.24	18.79	18.19	17.74
	SD	6.98	9.26	5.78	6.35
CONT-HI	M	10.84	12.59	10.02	9,91
	SD	6.04	7.27	5.71	5.38

COMPONENT - *AMPLITUDE* N_1-P_2

Cz Location

		Total	Correct	Under	Over
QUAN	M	20.26	22.53	20.51	17.74
	SD	8.40	8.74	6.99	9.67
QUAL-HI	M	19.99	20.29	20.45	19.24
	SD	5.88	7.36	5.05	5.73
CONT-HI	M	13.63	15.23	13.38	12.28
	SD	4.50	6.90	2.19	2.99

Fz Location

QUAN	M	14,44	16.55	15.03	11.74
	SD	6.04	6.13	5.23	6.39
QUAL-HI	M	14.52	17.34	13.96	12.26
	SD	4.80	4.37	4.50	4.59
CONT-HI	M	11.28	12.66	10.65	10.53
	SD	4.40	6.08	2.47	4.14

Pz Location

QUAN	M	19.58	20.16	22.42	16.17
	SD	7.07	7.15	5.84	7.49
QUAL-HI	M	19.44	18.79	19.66	19.86
	SD	5.90	6.60	6.81	4.89
CONT-HI	M	13.38	14.83	12.91	12.41
	SD	3.99	4.41	3.93	3.71

COMPONENT - *AMPLITUDE* N_2

Cz Location

		Total	Correct	Under	Over
QUAN	M	14.21	17.00	16.13	9.50
	SD	7.91	10.12	6.25	5.07
QUAL-HI	M	12.85	16.02	10.27	12.28
	SD	8.27	10.96	7.61	5.22
CONT-HI	M	3.16	5.01	1.92	2.55
	SD	7.48	10.13	5.78	6.47

Fz Location

QUAN	M	6.75	9.86	7.02	3.37
	SD	6.77	7.21	7.40	4.45
QUAL-HI	M	6.03	9.82	3.53	4.74
	SD	7.22	8.23	6.54	5.97
CONT-HI	M	0.98	1.52	0.22	1.20
	SD	4.51	7.12	3.39	1.87

Pz Location

QUAN	M	13.35	16.02	13.94	10.11
	SD	7.95	9.04	8.01	6.41
QUAL-HI	M	12.94	16.19	10.91	11.70
	SD	8.42	10.80	8.32	5.33
CONT-HI	M	4.29	5.52	3.53	3.62
	SD	7.71	9.89	8.22	5.19

COMPONENT - *AMPLITUDE* P_2-N_2

Cz Location

		Total	Correct	Under	Over
QUAN	M	-4.91	-5.25	-3.69	-5.79
	SD	5.58	6.66	5.06	5.44
QUAL-HI	M	-6.19	-4.94	-8.18	-5.43
	SD	4.85	4.82	4.98	4.71
CONT-HI	M	-7.87	-8.14	-8.14	-7.33
	SD	5.27	6.82	3.78	5.48

Fz Location

QUAN	M	-6.22	-5.81	-7.11	-5.75
	SD	4.52	5.38	5.18	3.18
QUAL-HI	M	-7.22	-7.71	-8.07	-5.88
	SD	3.93	3.83	4.93	2.94
CONT-HI	M	-7.80	-9.33	-7.56	-6.51
	SD	4.67	5.53	4.19	4.35

Pz Location

QUAN	M	-4.64	-3.53	-6.06	-4.34
	SD	4.73	5.01	4.76	4.68
QUAL-HI	M	-5.30	-2.59	-7.27	-6.04
	SD	5.85	2.91	8.19	4.86
CONT-HI	M	-6.61	-7.07	-6.48	-6.28
	SD	3.72	4.89	3.92	2.41

COMPONENT - *AMPLITUDE* P_3

Cz Location

		Total	Correct	Under	Over
QUAN	M	26.11	29.89	26.02	22.44
	SD	11.06	13.46	10.70	8.64
QUAL-HI	M	23.69	26.31	21.81	22.95
	SD	8.65	9.86	9.50	6.79
CONT-HI	M	9.64	9.68	10.09	9.15
	SD	7.85	10.10	6.28	7.78

Fz Location

QUAN	M	20.80	23.78	20.01	17.63
	SD	11.04	14.08	9.38	9.63
QUAL-HI	M	17.48	19.28	16.33	16.82
	SD	6.23	7.22	5.94	5.86
CONT-HI	M	7.71	7.42	8.23	7.49
	SD	5.28	5.81	4.58	6.04

Pz Location

QUAN	M	26.44	31.10	26.31	21.92
	SD	9.36	11.37	7.72	7.12
QUAL-HI	M	24.72	28.61	23.00	22.55
	SD	7.83	10.38	5.62	5.99
CONT-HI	M	9.62	10.36	10.56	7.96
	SD	8.09	11.97	5.91	5.66

COMPONENT - *AMPLITUDE* N_1-P_3

Cz Location

		Total	Correct	Under	Over
QUAN	M	27.25	30.16	26.71	24.88
	SD	10.16	11.33	10.31	9.37
QUAL-HI	M	24.64	25.64	23.80	24.47
	SD	7.24	7.52	8.80	6.01
CONT-HI	M	12.23	11.76	13.40	11.54
	SD	6.84	8.19	6.87	6.08

Fz Location

QUAN	M	22.27	24.65	21.90	20.24
	SD	10.41	13.74	7.45	10.02
QUAL-HI	M	18,74	19.08	18.68	18.45
	SD	5.41	6.41	5.55	4.89
CONT-HI	M	10.21	9.24	11.09	10.31
	SD	5.53	6.25	5.39	5.52

Pz Location

QUAN	M	28.02	31.70	28.72	23.65
	SD	8.64	10.31	7.20	7.01
QUAL-HI	M	25.92	28.61	24.47	24.68
	SD	6.63	8.47	5.91	5.05
CONT-HI	M	12.17	12.59	13.44	10.47
	SD	5.76	8.39	4.82	3.15

COMPONENT - *AMPLITUDE* N_3

Cz Location

		Total	Correct	Under	Over
QUAN	M	4.22	8.30	2.57	1.79
	SD	6.78	4.06	6.55	7.93
QUAL-HI	M	2.36	6.08	1.90	-0.89
	SD	6.85	4.15	5.84	8.63
CONT-HI	M	-1.38	-0.29	-2.39	-1.47
	SD	4.32	5.71	3.59	3.63

Fz Location

QUAN	M	-0.45	2.52	-0.60	-2.05
	SD	6.42	5.29	5.18	8.26
QUAL-HI	M	-0.32	1.70	1.41	-3.80
	SD	5.99	4.52	6.11	6.25
CONT-HI	M	-1.63	-2.70	-2.08	-0.11
	SD	3.66	4.27	3.85	2.62

Pz Location

QUAN	M	8.84	12.86	7.27	6.39
	SD	4.98	2.34	5.30	4.45
QUAL-HI	M	7.51	11.72	6.86	3.96
	SD	5.65	3.58	4.08	6.35
CONT-HI	M	0.53	0.82	0.58	0.17
	SD	4.76	6.73	3.96	3.63

COMPONENT - *AMPLITUDE* P_4

Cz Location

		Total	Correct	Under	Over
QUAN	M	13.53	13.42	14.38	12.79
	SD	4.71	4.84	4.81	4.99
QUAL-HI	M	11.93	10.91	12.68	12.19
	SD	3.51	3.59	3.11	4.00
CONT-HI	M	5.01	4.34	5.32	5.63
	SD	4.81	5.60	4.66	4.69

Fz Location

QUAN	M	8.07	8.95	8.74	6.51
	SD	4.70	4.50	4.35	4.42
QUAL-HI	M	6.62	6.64	7.11	6.10
	SD	4.00	2.49	5.43	4.03
CONT-HI	M	3.28	2.64	3.08	4.13
	SD	3.31	3.85	3.33	2.97

Pz Location

QUAN	M	17.60	18.19	18.50	
	SD	3.77	2.68	5.06	3.20
QUAL-HI	M	14.91	14.96	14.96	14.81
	SD	4.59	5.29	3.95	5.08
CONT-HI	M	6.92	7.33	6.93	6.48
	SD	3.89	4.55	4.29	3.20

COMPONENT - *AMPLITUDE* N_1-P_4

Cz Location

		Total	Correct	Under	Over
QUAN	M	14.67	13.69	15.08	15.23
	SD	4.73	4.23	5.32	5.06
QUAL-HI	M	12.88	10.24	14.67	13.71
	SD	5.38	5.76	5.45	4.45
CONT-HI	M	7.69	6.42	8.63	8.03
	SD	5.00	6.17	5.57	3.19

Fz Location

QUAN	M	9.53	9.82	9.64	9.12
	SD	4.11	4.01	4.38	4.45
QUAL-HI	M	7.88	6.44	9.46	7.74
	SD	5.04	4.34	6.35	4.36
CONT-HI	M	5.78	4.45	5.95	6.95
	SD	4.06	5.79	3.25	2.53

Pz Location

QUAN	M	19.19	18.79	20.92	17.85
	SD	4.61	2.73	6.06	4.46
QUAL-HI	M	16.11	14.96	16.44	16.93
	SD	6.24	7.15	6.75	5.36
CONT-HI	M	9.46	9.57	9.82	8.99
	SD	3.55	3.18	4.97	2.49

COMPONENT - *AMPLITUDE POST FEEDBACK*

Cz Location

		Total	Correct	Under	Over
QUAN	M	4.97	6.64	5.52	2.75
	SD	6.26	7.19	6.20	5.42
QUAL-HI	M	4.28	5.45	3.78	3.60
	SD	4.19	4.34	3.64	4.80
CONT-HI	M	-0.27	1.14	-1.05	-0.91
	SD	3.89	4.36	4.04	3.30

Fz Location

QUAN	M	2.72	4.56	2.55	1.05
	SD	5.72	5.01	5.62	6.61
QUAL-HI	M	2.01	1.52	1.81	2.70
	SD	4.58	5.36	4.93	3.89
CONT-HI	M	-0.08	0.15	-0.87	0.47
	SD	2.85	2.82	3.30	2.61

Pz Location

QUAN	M	5.82	8.25	5.32	3.89
	SD	4.22	5.17	3.22	3.17
QUAL-HI	M	4.43	6.73	3.40	3.15
	SD	4.35	3.72	3.69	5.07
CONT-HI	M	-0.92	0.67	-0.98	-2.46
	SD	4.42	4.64	4.47	4.13

Appendix E. Means and standard deviations of the frontal, central, and parietal data, Experiment 3-2.

COMPONENT - *AMPLITUDE PRE FEEDBACK*

Cz Location

		Total	Correct	Incorrect
QUAN	M	-3.46	-4.29	-2.64
	SD	4.63	3.99	5.34
QUAL-HI	M	-3.56	-4.27	-2.86
	SD	4.49	5.38	3.61
QUAL-LO	M	-2.45	-2.77	-2.12
	SD	5.59	6.53	4.91
CONT-LO	M	-0.78	-0.80	-0.76
	SD	3.48	3.32	3.87

Fz Location

QUAN	M	-0.31	-1.00	0.38
	SD	4.11	3.74	4.59
QUAL-HI	M	-0.81	-1.38	-0.24
	SD	3.69	4.53	2.83
QUAL-LO	M	-0.75	-1.63	0.13
	SD	4.91	5.31	4.66
CONT-LO	M	0.43	-0.31	1.11
	SD	2.81	2.84	2.76

Pz Location

QUAN	M	-5.90	-6.69	-5.12
	SD	3.57	2.89	4.19
QUAL-HI	M	-6.25	-8.23	-4.27
	SD	3.79	2.98	3.59
QUAL-LO	M	-5.41	-5.52	-5.30
	SD	4.43	5.23	3.84
CONT-LO	M	-2.62	-3.13	-2.12
	SD	3.67	3.47	4.04

COMPONENT - *AMPLITUDE* N_1

Cz Location

		Total	Correct	Incorrect
QUAN	M	-1.28	-0.26	-2.30
	SD	3.59	3.98	3.07
QUAL-HI	M	-0.50	0.67	-1.67
	SD	4.75	5.17	4.31
QUAL-LO	M	-1.05	0.11	-2.21
	SD	4.64	5.16	4.04
CONT-LO	M	-2.36	-2.19	-2.52
	SD	3.67	4.23	3.30

Fz Location

QUAN	M	-1.79	-0.87	-2.70
	SD	4.41	4.55	4.37
QUAL-HI	M	-1.10	0.20	-2.41
	SD	4.72	5.50	3.69
QUAL-LO	M	-1.80	-1.32	-2.28
	SD	3.55	3.65	3.64
CONT-LO	M	-2.28	-2.19	-2.37
	SD	2.42	1.94	2.97

Pz Location

QUAN	M	-1.80	-0.60	-2.99
	SD	3.89	3.21	4.35
QUAL-HI	M	-1.23	0.00	-2.46
	SD	4.76	4.90	4.60
QUAL-LO	M	-0.40	0.73	-1.54
	SD	4.75	5.26	4.20
CONT-LO	M	-2.60	-2.86	-2.34
	SD	3.67	3.85	3.73

COMPONENT - *AMPLITUDE* P_2

Cz Location		Total	Correct	Incorrect
QUAN	M	19.36	22.26	16.46
	SD	10.35	11.35	9.02
QUAL-HI	M	19.37	20.96	17.78
	SD	9.04	10.50	7.69
QUAL-LO	M	18.30	20.69	15.90
	SD	6.88	8.32	4.36
CONT-LO	M	11.17	11.94	10.40
	SD	5.82	6.16	5.76

Fz Location				
QUAN	M	13.24	15.68	10.80
	SD	7.53	7.91	6.73
QUAL-HI	M	13.96	17.54	10.38
	SD	8.05	8.03	6.72
QUAL-LO	M	11.84	14.61	9.08
	SD	5.31	5.07	4.15
CONT-LO	M	8.62	9.37	7.87
	SD	4.72	6.15	2.93

Pz Location				
QUAN	M	18.53	19.55	17.52
	SD	8.71	10.12	7.61
QUAL-HI	M	18.28	18.79	17.76
	SD	8.15	9.25	7.48
QUAL-LO	M	18.13	19.80	16.46
	SD	6.45	7.76	4.74
CONT-LO	M	11.62	12.50	10.74
	SD	5.47	5.29	5.86

COMPONENT - *AMPLITUDE* N_1-P_2

Cz Location

		Total	Correct	Incorrect
QUAN	M	20.65	22.53	18.77
	SD	8.48	8.74	8.35
QUAL-HI	M	19.88	20.29	19.46
	SD	6.61	7.36	6.25
QUAL-LO	M	19.35	20.58	18.12
	SD	4.23	4.71	3.57
CONT-LO	M	13.53	14.14	12.93
	SD	4.97	6.16	3.77

Fz Location

QUAN	M	15.03	16.55	13.51
	SD	6.52	6.13	6.94
QUAL-HI	M	15.07	17.34	12.79
	SD	5.48	4.37	5.79
QUAL-LO	M	13.64	15.93	11.36
	SD	3.71	2.95	2.99
CONT-LO	M	10.90	11.56	10.24
	SD	5.12	7.07	2.29

Pz Location

QUAN	M	20.33	20.16	20.51
	SD	7.53	7.15	8.38
QUAL-HI	M	19.51	18.79	20.22
	SD	6.62	6.60	7.01
QUAL-LO	M	18.53	19.06	18.01
	SD	4.67	4.31	5.24
CONT-LO	M	14.23	15.37	13.08
	SD	4.35	4.64	4.00

COMPONENT - *AMPLITUDE N_2*

Cz Location

		Total	Correct	Incorrect
QUAN	M	14.66	17.00	12.32
	SD	8.36	10.12	5.90
QUAL-HI	M	13.87	16.02	11.72
	SD	9.06	10.96	6.73
QUAL-LO	M	13.00	16.87	9.12
	SD	7.57	7.79	5.27
CONT-LO	M	4.21	3.26	5.16
	SD	6.83	5.94	7.91

Fz Location

QUAN	M	6.52	9.86	3.17
	SD	7.15	7.21	5.65
QUAL-HI	M	7.20	9.82	4.58
	SD	7.55	8.23	6.23
QUAL-LO	M	6.03	9.82	2.23
	SD	6.79	6.19	5.27
CONT-LO	M	0.23	1.05	-0.58
	SD	4.67	5.64	3.67

Pz Location

QUAN	M	14.01	16.02	12.01
	SD	8.63	9.04	8.29
QUAL-HI	M	14.30	16.19	12.41
	SD	8.96	10.80	6.88
QUAL-LO	M	14.21	18.12	10.31
	SD	7.18	7.13	5.00
CONT-LO	M	4.69	5.92	3.46
	SD	7.51	7.52	7.80

COMPONENT - *AMPLITUDE* P_2-N_2

Cz Location

		Total	Correct	Incorrect
QUAN	M	-4.69	-5.25	-4.13
	SD	5.98	6.66	5.63
QUAL-HI	M	-5.50	-4.94	-6.06
	SD	4.69	4.82	4.82
QUAL-LO	M	-5.30	-3.82	-6.78
	SD	3.74	2.61	4.26
CONT-LO	M	-6.95	-8.68	-5.23
	SD	6.12	3.55	7.80

Fz Location

QUAN	M	-6.72	-5.81	-7.63
	SD	5.25	5.38	5.31
QUAL-HI	M	-6.75	-7.71	-5.79
	SD	3.92	3.83	4.02
QUAL-LO	M	-5.81	-4.79	-6.84
	SD	3.26	3.27	3.11
CONT-LO	M	-8.39	-8.32	-8.45
	SD	3.12	3.46	2.98

Pz Location

QUAN	M	-4.52	-3.53	-5.50
	SD	5.25	5.01	5.64
QUAL-HI	M	-3.97	-2.59	-5.34
	SD	5.18	2.91	6.69
QUAL-LO	M	-3.91	-1.67	-6.15
	SD	4.28	1.24	5.12
CONT-LO	M	-6.92	-6.57	-7.27
	SD	3.20	3.71	2.81

COMPONENT - *AMPLITUDE* P_3

Cz Location

		Total	Correct	Incorrect
QUAN	M	27.90	29.89	25.91
	SD	11.62	13.46	9.96
QUAL-HI	M	23.93	26.31	21.54
	SD	9.24	9.86	8.54
QUAL-LO	M	22.81	26.40	19.22
	SD	6.78	6.88	4.64
CONT-LO	M	9.27	11.43	7.11
	SD	8.94	10.29	7.39

Fz Location

QUAN	M	21.74	23.78	19.71
	SD	12.00	14.08	10.04
QUAL-HI	M	17.45	19.28	15.61
	SD	6.73	7.22	6.10
QUAL-LO	M	16.05	19.26	12.84
	SD	6.45	5.99	5.46
CONT-LO	M	6.73	7.24	6.22
	SD	5.33	6.39	4.40

Pz Location

QUAN	M	28.01	31.10	24.92
	SD	10.21	11.37	8.50
QUAL-HI	M	25.21	28.61	21.81
	SD	8.65	10.38	5.12
QUAL-LO	M	24.00	28.19	19.82
	SD	6.46	6.25	3.23
CONT-LO	M	11.16	13.71	8.61
	SD	9.19	10.73	7.13

COMPONENT - *AMPLITUDE* N_1-P_3

Cz Location

		Total	Correct	Incorrect
QUAN	M	29.18	30.16	28.21
	SD	9.61	11.33	8.21
QUAL-HI	M	24.43	25.64	23.22
	SD	7.04	7.52	6.80
QUAL-LO	M	23.86	26.29	21.43
	SD	4.38	2.44	4.66
CONT-LO	M	11.63	13.62	9.64
	SD	7.20	7.77	6.46

Fz Location

QUAN	M	23.53	24.65	22.42
	SD	10.84	13.74	7.75
QUAL-HI	M	18.56	19.08	18.03
	SD	5.60	6.41	5.04
QUAL-LO	M	17.85	20.58	15.12
	SD	5.17	3.90	5.01
CONT-LO	M	9.01	9.42	8.59
	SD	6.02	7.32	4.87

Pz Location

QUAN	M	29.81	31.70	27.92
	SD	8.57	10.31	6.54
QUAL-HI	M	26.44	28.61	24.27
	SD	6.83	8.47	4.18
QUAL-LO	M	24.41	27.45	21.36
	SD	4.56	3.82	2.99
CONT-LO	M	13.77	16.58	10.96
	SD	8.11	9.79	5.21

COMPONENT - *AMPLITUDE* N_3

Cz Location

		Total	Correct	Incorrect
QUAN	M	4.96	8.30	1.65
	SD	6.30	4.06	6.58
QUAL-HI	M	3.46	6.08	0.85
	SD	5.83	4.15	6.33
QUAL-LO	M	2.55	6.13	-1.02
	SD	6.97	3.95	7.70
CONT-LO	M	-1.75	-0.44	-3.06
	SD	6.66	9.13	2.82

Fz Location

QUAN	M	0.11	2.52	-2.30
	SD	6.35	5.29	6.71
QUAL-HI	M	0.01	1.70	-1.67
	SD	5.50	4.52	6.15
QUAL-LO	M	-0.92	1.72	-3.58
	SD	7.27	6.11	7.74
CONT-LO	M	-3.36	-5.21	-1.52
	SD	6.14	4.98	6.95

Pz Location

QUAN	M	9.61	12.86	6.35
	SD	5.31	2.34	5.54
QUAL-HI	M	8.36	11.72	5.01
	SD	5.21	3.58	4.44
QUAL-LO	M	7.68	11.32	4.05
	SD	5.82	3.55	5.45
CONT-LO	M	-0.41	1.25	-2.08
	SD	5.65	7.14	3.35

COMPONENT - *AMPLITUDE* P_4

Cz Location

		Total	Correct	Incorrect
QUAN	M	13.45	13.42	13.49
	SD	4.70	4.84	4.90
QUAL-HI	M	12.06	10.91	13.20
	SD	3.78	3.59	3.84
QUAL-LO	M	11.06	12.70	9.42
	SD	4.36	3.22	4.91
CONT-LO	M	4.12	5.90	2.34
	SD	6.03	6.93	4.76

Fz Location

QUAN	M	7.86	8.95	6.78
	SD	5.13	4.50	5.79
QUAL-HI	M	6.93	6.64	7.22
	SD	3.95	2.49	5.20
QUAL-LO	M	5.70	8.05	3.35
	SD	6.43	4.60	7.41
CONT-LO	M	1.46	1.34	1.58
	SD	3.11	2.97	3.45

Pz Location

QUAN	M	17.71	18.19	17.22
	SD	4.17	2,68	5.44
QUAL-HI	M	14.84	14.96	14.72
	SD	4.95	5.29	4.95
QUAL-LO	M	15.21	17.43	13.00
	SD	5.68	6.13	4.52
CONT-LO	M	6.48	6.91	6.06
	SD	4.49	4.97	4.25

COMPONENT - *AMPLITUDE* N_1-P_4

Cz Location

		Total	Correct	Incorrect
QUAN	M	14.74	13.69	15.79
	SD	4.52	4.23	4.84
QUAL-HI	M	12.56	10.24	14.87
	SD	5.70	5.76	4.93
QUAL-LO	M	12.11	12.59	11.63
	SD	6.24	5.17	7.50
CONT-LO	M	6.48	8.10	4.87
	SD	4.55	4.22	4.55

Fz Location

QUAN	M	9.65	9.82	9.48
	SD	3.85	4.01	3.94
QUAL-HI	M	8.04	6.44	9.64
	SD	5.39	4.34	6.14
QUAL-LO	M	7.50	9.35	5.63
	SD	6.68	5.40	7.65
CONT-LO	M	3.74	3.53	3.96
	SD	3.43	3.42	3.66

Pz Location

QUAN	M	19.51	18.79	20.22
	SD	4.53	2.73	5.94
QUAL-HI	M	16.07	14.96	17.18
	SD	6.54	7.15	6.15
QUAL-LO	M	15,61	16.69	14.54
	SD	7.53	7.57	7.86
CONT-LO	M	9.09	9.77	8.41
	SD	4.10	4.25	4.11

COMPONENT - *AMPLITUDE POST FEEDBACK*

Cz Location

		Total	Correct	Incorrect
QUAN	M	5.05	6.64	3.46
	SD	6.53	7.19	5.83
QUAL-HI	M	4.87	5.45	4.29
	SD	4.07	4.34	3.99
QUAL-LO	M	2.09	1.81	2.37
	SD	5.36	6.48	4.41
CONT-LO	M	-1.41	-0.29	-2.52
	SD	3.48	4.10	2.51

Fz Location

QUAN	M	2.75	4.56	0.94
	SD	6.02	5.01	6.70
QUAL-HI	M	2.15	1.52	2.79
	SD	4.42	5.36	3.50
QUAL-LO	M	0.38	0.69	0.06
	SD	6.78	6.09	6.46
CONT-LO	M	-0.99	-0.17	-1.81
	SD	2.48	2.65	2.16

Pz Location

QUAN	M	6.19	8.25	4.13
	SD	4.61	5.17	3.03
QUAL-HI	M	5.02	6.73	3.31
	SD	4.88	3.72	5.51
QUAL-LO	M	5.33	6.66	4.00
	SD	4.95	5.85	3.75
CONT-LO	M	-0.85	0.00	-1.70
	SD	2.41	1.38	2.98