THE NATURE OF CORTICAL ACTIVITY
IN A STIMULUS-RESPONSE PARADIGM

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CURRICULUM STUDIORUM

Carol Doutriaux was born May 5, 1949, in Niagara Falls, New York. She received her Baccalauréat ès Philosophie-Lettres, mention Bien, from l'Académie de Lyon, France in 1968. In 1971, she received the Bachelor of Arts degree in biology from Oberlin College, Oberlin, Ohio.

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INTRODUCTION

Ever since the discovery that the human brain exhibits electrical activity in the form of constantly shifting, tiny potential changes, scientists have been curious as to the meaning of this activity and its relation to overt human behavior. Modern electronic amplifiers have permitted ever more precise examination of ongoing cortical activity, leading to the discovery that the form of this activity does indeed correlate with the different stages of arousal of the individual. Even more recently, the technique of recording, digitizing, and summating short periods of EEG with specially adapted computers, has confirmed the previous speculation that predictable changes in cortical activity also take place in connection with repetitive external stimulation. That is, by triggering the computer to record and summate the EEG during a brief period consistently coordinated with sensory stimulation, it is possible to obtain, after many repeated trials, a cancellation of random activity while nonrandom elements emerge much enhanced. Such a characteristic series of reliable time-locked elements elicited by peripheral stimulation is commonly called an "evoked potential." Similarly, summation of EEG aligned according to the onset of voluntary movement has revealed non-random elements preceding and following that movement, and called a "motor potential."

The natural sequel to such consistent and logical findings is, of course, to attempt to interpret them on the physiological level, and to try to relate them to more observable macroscopic events. One method for clarifying these relationships is by combining the two simple patterns, stimulus sensation plus voluntary movement, into one sequence. A simple stimulus-response paradigm comprises the first step toward the purposeful, integrated behavior typical of human beings. Being simple, it lends itself well to research in a field still in its infancy; apparently accessible to the understanding, it invites attempts to solve its mystery; model for more complex behaviors, it is an exciting incentive to further research.

As is so often the case, however, this simple paradigm has turned out to be in itself complex. As a result, the literature dealing with changes in the evoked potential associated with motor response to the trigger stimulus is full of inconsistencies and unexplained variables. The present series of experiments was designed for the purpose of examining the effect of several well-defined variables on the waveform of the visual evoked potential. Most important is the "response condition" variable; that is, the simple stimulus-response paradigm is examined in two forms--as a finger reaction and as a foot reaction--as it relates to changes in latency and amplitude of the principle elements of the evoked potential. Secondly, this comparison is made using visual evoked potentials from three different areas of the motor cortex, in an effort to pinpoint differential modes of activity in different parts of the brain. Two more variables, reaction speed and position in time of the series, are introduced in the statistical analyses principally in order to ascertain the effectiveness of controls. These controls are highly important, for it is in the effective control of arousal and normal inter-individual variability that these experiments particularly distinguish themselves from others previously published. The examination of these particular variables across three different locations on the motor cortex is also a unique innovation. The purpose of the experiments was to obtain a global picture of brain activity through the stimulus-response paradigm, in an effort to better understand the significance of reliable time-locked elements and, eventually, to make a small step toward understanding the complex relations linking the electrical activity of the brain to human behavior.

This paper begins with a review of the literature specifically dealing with the search for nonrandom cortical activity preceding movement. The variety of experimental designs encountered, and the multitude of factors appearing to relate in some way to this movement, testify to the complexity of the problem and to the confusion now reigning in the field. Three of these related factors having been chosen for particular study here, the literature treating evoked potentials and cortical location, attention or arousal, and individual variability is also reviewed. Chapter I concludes with a discussion of the theoretical basis for the experimental design chosen, and presentation of the null hypotheses governing the experiments. Chapter II describes the procedures followed in obtaining and analyzing the data. The importance of the many controls imposed in order to isolate simple phenomena is emphasized. In Chapter III, the results of the various analyses are described, and their significance discussed. The implications for further research are numerous, and some of them are pointed out in this discussion. In three appendices, the detailed results of reliability studies and analyses of variance, already summarized in the text, are given in their entirety.

CHAPTER I

REVIEW OF THE LITERATURE

In the past two decades, the study of the electrical activity of the cortex has developed enormously. Particularly with the discovery of computer averaging techniques, permitting relatively easy detection of nonrandom events which had previously been obscured by normal ongoing random activity, research in this field has blossomed. Stimulating the cortex with some external stimulus, such as a light flash or a sudden noise, has been found to elicit a characteristic and reliable series of potential changes in the thirty to 500 milliseconds following which has been called, appropriately, the "evoked potential." The reports of research dealing with effects of different physiological, psychological, internal and external variables on evoked potentials could certainly fill a large library, yet the controversies and problems still to be solved are even more numerous. Since, however, a few rather well-defined variables have been chosen for study in the present experiments, it is the literature treating most specifically these chosen variables which will be reviewed here.

1. Motor Activation

If a reliable sequence of cortical activity follows external stimulation, it is logical that internal, voluntary activity should be equally discernable, provided limited periods of apparently random activity preceding and following a repetitive act could be aligned and summated so as to reveal the nonrandom elements obscured within them. Nevertheless, considerably less attention has so far been paid to detection of voluntary acts, probably because of the greater difficulty involved in choosing precise periods for summation.

A first and classic attempt to discern cortical activity accompanying voluntary movement was reported by Bates[1] in 1951, even before the advent of computer summation techniques. He superimposed EEG traces aligned according to the onset of EMG activity when the subject periodically clenched a small cylinder in his hand. Using such a crude technique, it is remarkable that he did detect a slight, but reliable, potential change following the movement, which he interpreted as representing the arrival of afferent impulses from the periphery. No reliable cortical activity could be observed preceding the movement.

By 1966, the technique of computer summation of EEG activity was well-enough developped to permit its application in experiments very similar to Bates' and, through a vastly improved signal-to-noise ratio, to permit more precise observation and identification of the potential changes. Gilden, Vaughan, and Costa[2] were the first to describe a characteristic waveform accompanying repetitive movement, which they called the "motor potential." It was particularly marked by an abrupt negative shift from the baseline fifty to 150 milliseconds before the onset of a muscle contraction, and by a large positive peak following. The negative wave they interpreted as a sign of corticospinal discharge, and the positive wave as the

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[1] J.A.V.Bates, "Electrical Activity of the Cortex Accompanying Movement", in Journal of Physiology (London), Vol. 113, 1951, pp. 240-257.

[2] L.Gilden, H.G.Vaughan Jr., and L.D.Costa, "Summated Human EEG Potentials with Voluntary Movement", in Electroencephalography and Clinical Neurophysiology, Vol. 20, 1966, pp. 433-438.

afferent feedback already seen by Bates. These results were independently corroborated, at least in their essential aspects, by Ertl[3] in his description of "command potentials."

The discovery of the motor potential, and concurrent work on the sensory evoked potential, thus opened up brand new possibilities for understanding the nature of cortical functioning. It seemed possible now to witness, and to specify, such physiological phenomena as the conduction time of nerve impulses--both afferently, from sense organ to cortex, and efferently, from cortex to various muscle groups. It remained, however, to combine these two separate events into one experiment, which hopefully would permit two important distinctions: 1) that which differentiates these two types of activation, "passive" and "voluntary", in cortical records, and 2) that which separates the integration, or processing, time needed by the cortex, from simple conduction time in a situation where afferent stimulation elicits a voluntary response. As is often the case, this combination of two apparently simple phenomena into a single more complex event has raised many more problems than it has solved.

Vaughan, Costa, Gilden and Schimmel[4] in 1965 tried to rediscover their "motor potential" in the context of a simple reaction task where the subject had to respond to a flash of light or to a "click" by making a quick

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[3] John Ertl, Command Potentials, unpublished Ph.D. thesis presented to the Faculty of Psychology and Education of the University of Ottawa, Ontario, 1966, 18 p.

[4] H.G.Vaughan, L.D.Costa, L.Gilden, and H.Schimmel, "Identification of Sensory and Motor Components of Cerebral Activity in Simple Reaction-Time Tasks", in Proceedings of the 73rd Conference of the American Psychological Association, Vol. 1, 1965, pp. 179-180.

hand or foot movement. The averaged evoked response to a block of stimuli followed by no reaction was subtracted from the averaged evoked response to stimuli followed by a voluntary reaction. The resulting curve looked much like the summated "motor potential" and was interpreted by the authors as such. From their data, they reported nervous conduction time from cortex to hand to take from 30 to 40 milliseconds, from cortex to foot to take 60 to 80 msec, and finally they estimated the central delay time to be 20 to 60 msec.

All of these results would seem to be the logical consequence of combining previous experimental results. However, subsequent investigation has failed to confirm the reported results of Vaughan _et_. _al_., and has led to considerable controversy and confusion. Certain weaknesses in their procedure have been revealed as possibly significant, and have led to intense questioning of the validity of their results. For example, their only control on attention and arousal level through the various blocks of experimental conditions was by having the subject count the stimuli mentally through each series. Yet it now appears that the amplitude of the various evoked potential components may be very sensitive to fluctuations in arousal. In addition, the intuitive nature of their analysis (global examination of subtracted curves), and the lack of statistical evidence, cast some doubt on the validity of their findings, and of their concrete and specific interpretations.

Experimentation thus continued. Donchin and Lindsley[5], reporting

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[5] E.Donchin and D.B.Lindsley, "Average Evoked Potentials and Reaction Times to Visual Stimuli", in _Electroenceph. Clin. Neurophysiol._, Vol. 20, 1966, pp. 217-223.

significant amplitude differences between the evoked potentials obtained under response and no-response conditions, but finding no time-locked differences preceding reaction, concluded that the amplitude differences reflected changes in cortical excitability, in the non-specific arousal system of the cortex. Wilkinson and Morlock[6] applied statistical analyses to specific components of auditory evoked potentials obtained under various response conditions, and claimed to confirm the existence of a large wave which they called a "motor potential," during the response condition. Nevertheless, its location and form were not precisely enough defined to be considered a confirmation of the specific assertions of Vaughan _et.al_. The authors, in fact, preferred to compare it to the component interpreted by Bates and by Gilden _et.al_. as kinaesthetic feedback. The fact that their statistical analyses revealed no correlation between speed of reaction time and either amplitude or latency of the evoked potential components casts further doubt upon the relation of their so-called "motor potential" wave to the time-locked negative shift of Vaughan _et.al_.

Karlin, Martz, and Mordkoff[7,8] attempted to sort out this confused state of affairs, and to separate the effects related to an overt motor response from those caused by prior development of "readiness" (related to

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[6] R.T.Wilkinson and H.C.Morlock, "Auditory Evoked Response and Reaction Time", in _Electroenceph. Clin. Neurophysiol._, Vol. 23, 1967, pp. 50-56.

[7] L.Karlin, M.J.Martz, and A.M.Mordkoff, "Motor Performance and Sensory Evoked Potentials", in _Electroenceph. Clin. Neurophysiol._, Vol. 28, 1970, pp. 307-313.

[8] L.Karlin, M.J.Martz, S.E.Brauth, and A.M.Mordkoff, "Auditory Evoked Potentials, Motor Potentials, and Reaction Times", in _Electroenceph. Clin. Neurophysiol._, Vol. 31, 1971, pp. 129-136.

the contingent negative variation reported by Walter[9] and others). They compared the effects on specific evoked potential components of actually making an overt motor response, and of withholding it. They thereby tried to control for the effects of general readiness and to separate them from the effects of overt action. Their results cast doubt on the possibility of there being a motor potential specifically related to pyramidal activation, as claimed by Vaughan et.al., for the negative shift noted in certain components during the overt response condition appeared also to be present in the withheld response condition. Supported by a rigorous statistical analysis of their data, the authors concluded that there were no effects on the evoked potential attributable to the specific time characteristics of the task (fast or slow reaction, simple or choice response condition) or to the motor response itself. They therefore claimed the observed negative shift to be related only to the development of an excitatory state associated with the intention to respond. The differences in response and no-response conditions seemed not to reflect simple modification of the evoked potential by a motor potential, but to arise from a more generalized "mobilization" effect. Therefore, they concluded, specific inferences concerning the timing of cortical processes during a simple reaction task are not likely to be supportable.

There remain, obviously, many questions to be answered. If Gilden et.al. and Ertl are right in asserting the existence of a motor potential

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[9] W.G.Walter, R.Cooper, V.J.Aldridge, W.C.McCallum, and A.L.Winter, "Contingent Negative Variation: an Electrical Sign of Sensorimotor Association and Expectancy in the Human Brain", in Nature, Vol. 203, 1964, pp.380-384.

prior to a repetitive voluntary act, why does its presence become so dubious when placed in the context of reaction to a sensory stimulus? Is the fact that reaction times are often rather widely distributed, and summation usually initiated with respect to stimulus onset rather than muscle activation, solely responsible for the apparent disappearance of the motor potential? Is the simple reaction to stimulus too trivial a task to be mediated by the cortex, being reflected at the spinal reflex level, and attaining the cortex only as afferent feedback? Might the use of different response modalities, and the requirement of decision on the part of the subject as to which to use bring out cortical activity not heretofore noted? Might the small number of trials generally attempted with one individual in this rather boring experimental situation be insufficient to reveal the small reliable elements set in a background of noise? At this time, the state of knowledge on all these points is unmistakably confused. Given the great variation in reported effects of motor reaction on the form of the evoked potential, independent corroboration of results is needed. The present paper attempts to deal with a few of the questions raised by comparing evoked potential characteristics across three different response conditions.

2. Cortical Location

Since the very beginning of evoked potential studies, investigators have been intrigued by the similarities and differences between recordings obtained from different parts of the brain. Much time has been devoted to mapping these differences in an effort to hypothesize a source for characteristic evoked responses. The resulting theories have been very general, and occasionally conflicting: Vaughan and Ritter[10] suggest a dipolar layer as source, deep within the brain; Morrell and Morrell[11] claim that the source changes through life, with a deep midline source in infancy, and more lateral sources in adulthood. With relation to the human motor potential, Vaughan, Costa, and Ritter[12] have attempted a similar study. Finding somewhat more clear results, they concluded that the motor potential comes from a very localized source. Their results are interesting because of their consistency with earlier studies by Penfield, mapping after direct artificial stimulation of the cortex during surgery. That is, the points showing maximum potential change with the motor potential for hand, foot, and tongue movements lay close to the Rolandic fissure, in locations similar to those reported by Penfield. In addition, the time lag between the onset of the motor potential and the onset of muscle contraction was found to be greater not only for muscle groups further from the brain--indicating longer nervous conduction time--but also greater for points over the Rolandic cortex than posterior or anterior--pointing toward a localization of the motor potential source in this area.

There are, then, statistically significant and functionally meaningful differences in the evoked potentials and motor potentials recorded from different functional and topographical regions of the cortex. Now what about

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[10] H.G. Vaughan and W. Ritter, "The Sources of Auditory Evoked Responses Recorded from the Human Scalp", *Electroenceph. Clin. Neurophysiol.*, Vol. 28, 1970, pp. 360-367.

[11] F. Morrell and L. Morrell, "Spacial Distribution of Averaged Evoked Potentials in Man", in *Electroenceph. Clin. Neurophysiol.*, Vol. 18, 1965,pp.522-523.

[12] H.G. Vaughan, L.D. Costa, and W. Ritter, "Topography of the Human Motor Potential", in *Electroenceph. Clin.Neurophysiol.*, Vol.25, 1968, pp. 1-10.

the differences between comparable areas of the two hemispheres? This question appears to have been largely ignored in the literature. For example, Morrell and Morrell[13] mention that there are obvious differences between the evoked potential tracings which they obtained from the left and right motor cortex in a reaction-time paradigm, but make no further comment on the fact. Vaughan <u>et.al.</u>[14] note hemispheric differences in amplitude of the motor potential, the latter being more marked in the hemisphere contralateral to the site of motor activation, but they make no attempt to examine hemispheric differences in peak latencies.

Most experimentation relating to interhemispheric differences in cortical activity has been aimed at investigating intrinsic differences in overall functioning of the hemispheres in different people. Evoked potential studies have revealed quite consistently, for example, that verbal stimuli evoke a response of greater amplitude in the left hemisphere while nonverbal stimuli are associated with a larger amplitude response in the right hemisphere. Cohn[15] makes this distinction particularly clear, while Morrell and Salamy[16] make more precise the localization of these differences and relate them to hemispheric specialization of function. Equally consistent findings show that there are hemispheric differences associated with

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[13] L.K.Morrell and F.Morrell, "Evoked Potentials and Reaction Times: A Study of Intra-individual Variability", in <u>Electroenceph. Clin. Neurophysiol.</u> Vol. 20, 1966, p. 572.

[14] H.G. Vaughan, L.D. Costa, and W. Ritter, <u>op. cit.</u>

[15] R. Cohn, "Differential Cerebral Processing of Noise and Verbal Stimuli", in <u>Science</u>, Vol. 172, 1971, pp. 599-601.

[16] L.K. Morrell and J.G. Salamy, "Hemispheric Asymmetry of Electrocortical Responses to Speech Stimuli", in <u>Science</u>, Vol. 174, 1971, pp. 164-166.

level of intelligence. Rhodes, Dustman and Beck[17] have studied this particular variable, finding that the visual evoked response from the right central (C_4) location was consistently larger than that from the comparable left location in bright children. Dull children, on the other hand, showed no hemispheric differences in amplitude. Schenkenberg[18] confirmed that the right hemisphere gave generally larger amplitude responses than the left in subjects of average and above-average intelligence ranging from four to 86 years of age. Speculation as to the meaning of these differences has tended to relate them to attentional differences. That is, since the right parietal area seems to be important in the neurophysiology of attention[19], it is hypothesized that bright individuals function at a generally higher level of attention than dull ones[20], or that the dull individuals show a dysfunctioning reticular activating system.[21]

A few experiments have been designed to explore hemispheric differences related specifically to motor activation. Though without the aid of evoked response data, Jeeves and Dixon[22] designed an experiment in

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[17] L.E. Rhodes, R.E. Dustman, and E.C. Beck, "The Visual Evoked Response: A Comparison of Bright and Dull Children", in Electroenceph. Clin. Neurophysiol., Vol. 27, 1969, pp. 364-372.

[18] T. Schenkenberg, Visual, Auditory, and Somatosensory Evoked Responses of Normal Subjects from Childhood to Senescence, unpublished Ph.D. thesis presented to the Faculty of Psychology of the University of Utah, Utah, 1970.

[19] C.R. Evans and T.B. Mulholland, "Attention as a Concept in Neurophysiology", in Science, Vol. 163, 1969, pp. 495-496.

[20] L.E. Rhodes, R.E. Dustman, and E.C. Beck, op. cit.

[21] D.B. Lindsley, "Psychophysiology and Motivation", in Nebraska Symposium on Motivation, 1957, pp. 44-106.

[22] M.A. Jeeves and N.F. Dixon, "Hemispheric Differences in Response Rates to Visual Stimuli", in Psychonomic Science, Vol.20, 1970, pp. 249-251.

which the visual stimulus was sent to only one hemisphere at a time, in order to investigate the effects on reaction time with the right or left hand. They discovered that regardless of cerebral dominance visual stimulation going to the right hemisphere was responded to faster than stimulation going to the left hemisphere. In fact, they were able to rank four S-R conditions in order of speed of response from fastest to slowest:

> "(1) Right hemisphere receiving, left hemisphere initiating response (by right hand); (2) right hemisphere receiving, right hemisphere initiating response (by left hand); (3) left hemisphere receiving, left hemisphere initiating response (by right hand); (4) left hemisphere receiving, right hemisphere initiating response (by left hand)."[23]

From their data, they hypothesized that the sensory receiving area in the right hemisphere must process information faster than that area in the left hemisphere, while the motor area in the left hemisphere must be faster at initiating a response than that in the right hemisphere. They cite as support for this position the findings of Cernacek[24], who investigated the inapparent EMG activity often noted in the muscle contralateral to one which is voluntarily activated. He found this "contralateral motor irradiation" to occur in all his subjects, in 77.6% of the trials, and to occur most frequently from the dominant side to the subordinate side. He explained this phenomenon by hypothesizing that mirrored on the contralateral side tó the cortex activated in voluntary muscle flexion is an area of facilitation, where for an

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[23] M.A. Jeeves and N.F. Dixon, op. cit., p. 250.

[24] J. Cernacek, "Contralateral Motor Irradiation--Cerebral Dominance", in Archives of Neurology, Vol. 4, 1961, pp. 165-172.

instant the cortex is more easily excited. The communication he supposed to take place via the corpus callosum, as demonstrated already in animals by Bremer et. al.[25]

These studies, carried out without the aid of electroencephalographic equipment, offer stimulating possibilities for research using that more modern and precise tool. The importance of interhemispheric communication has been emphasized; the possibility of there being a pattern facilitating this communication, and consequent activation, has never been sufficiently explored. The present experiments attempt to further that exploration by incorporating a comparison of evoked potential peak latencies and amplitudes across three different cortical locations.

3. Attention, Arousal, and Reaction Speed

Attention, arousal, evoked potential amplitude and reaction speed are closely-linked concepts in evoked potential literature. Eason et.al.[26] early noted that the amplitude of evoked potentials obtained under conditions of physical or mental exercise was enhanced relative to that of evoked potentials recorded under quiescent conditions. They claimed that the visual evoked potential was a "reliable and valid index of activation level", and that changes in its waveform gave clues as to the type of exercise engaged in. This position was later modified and made more precise by two of

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[25] F. Bremer, J. Brihaye, and G. André-Balisaux, "Physiologie et Pathologie du Corps Calleux", in Archives Suisses de Neurologie et Psychiatrie, Vol. 78, 1956, pp. 31-87.

[26] R.G. Eason, L.R. Aiken, C.T. White, and M. Lichtenstein,"Activation and Behavior: II. Visually Evoked Cortical Potentials in Man as Indicators of Activation Level", in Perceptual and Motor Skills, Vol. 19, 1964, pp. 875-895.

the same researchers[27] when they designed experiments to distinguish the effects of general level of arousal from those associated with specific attention. Levels of arousal were distinguished by recording reaction times to visual stimuli with and without a threat of shock for poor performance. Levels of specific attention were varied by presenting the stimuli in either the right or the left visual field, and having the subject react to those in only one field at a time--with and without threat of shock for mistakes. The results indicated that the evoked potentials recorded under conditions of high arousal had greater amplitude than those obtained under conditions of low arousal. The reaction times, too, were shorter with high arousal. As for specific attention, those flashes to which a response was required evoked a response of greater amplitude than did those being ignored.

Many, but by no means all, research reports supported these general findings. Satterfield[28] reported to the conference of the American EEG Society in 1963 that when subjects were told to attend to one of every two identical stimuli, those stimuli to which they attended evoked a response of smaller amplitude than those which they ignored. Yet in an article published two years later[29], he demonstrated that with two different stimuli, the subject showed a larger response when he was attending to a particular stimulus than when he was not. The main difference between these two experiments lay in

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[27] R.G. Eason, M.R. Harter, and C.T. White, "Effects of Attention and Arousal on Visually Evoked Cortical Potentials and Reaction Time in Man", in Physiology and Behavior. Vol. 4, 1969, pp. 283-289.

[28] J.H. Satterfield and D. Cheatum, "Evoked Cortical Potential Correlates of Attention in Human Subjects", in Electroenceph. Clin. Neurophysiol., Vol.17, 1964, pp. 456-457.

[29] J.H. Satterfield, "Evoked Cortical Response Enhancement and Attention in Man: a Study of Responses to Auditory and Shock Stimuli", in Electroenceph. Clin. Neurophysiol., Vol. 19, 1965, pp. 470-475.

the means of assuring close attention to the stimuli. In the first, the subject had been asked to count meaningful stimuli. Other investigators[30], however, have come to prefer looking upon counting as a distraction rather than as a means of focussing attention, since it is associated with reduced evoked potential amplitudes. Therefore, in the second experiment, a discrimination task was incorporated to rivet attention on the proper stimuli. In this case, close attention was associated with a larger response. Such small differences in the controls applied emphasize the sensitivity of the evoked potential measure, and the importance of defining well the experimental variables.

Continuing the investigation, Morrell and Morrell[31] found faster reaction times to be associated with larger amplitude responses in a simple S-R paradigm. Considered in the light of Eason's findings, these results seemed to assure interchangeability between fast reactions, high arousal, and large amplitude evoked responses.

However, Haider, Spong, and Lindsley[32,33] found in another visual discrimination task that the evoked potential amplitude for correctly detected signals was larger than that for missed signals. They noted also irregular

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[30] E. Garcia-Austt, J. Bogacz, and A. Vanzulli, "Effects of Attention and Inattention Upon Visual Evoked Response", in Electroenceph. Clin. Neurophysiol., Vol. 17, 1964, pp. 136-143.

[31] L.K. Morrell and F. Morrell, op. cit.

[32] M. Haider, P. Spong, and D.B. Lindsley, "Attention, Vigilance, and Cortical Evoked Potentials in Humans", in Science, Vol. 145, 1964, pp. 180-182.

[33] M. Haider, P. Spong, and D.B. Lindsley, "Cortical Evoked Potentials during Visual Vigilance Task Performance", in Electroenceph. Clin. Neurophysiol. Vol. 17, 1964, p. 714.

fluctuations in attentiveness within the regular decrease in general arousal through the long experimental period, but they emphasized that the evoked potential amplitude changes were mostly dependent on specific trials--i.e., detections or misses. Davis[34], on the other hand, using an auditory stimulus, found the evoked potential to be enhanced only when the subject was required to make a difficult discrimination--and then it was enhanced for the entire series of stimuli, irrespective of specific stimulus characteristics. Donchin and Lindsley[35] produced more evidence for non-specific arousal being associated with faster reactions and larger amplitude visual evoked responses. The question was thus raised whether evoked potential amplitude could be taken as a general indicator of arousal, or whether its fluctuations only depended on specific task characteristics.

Due to the vagueness of the term "amplitude of the evoked response" and to the difficulty of explaining such varied experimental results, the more recent tendency has been to examine specific peaks in their relation to reaction time and to arousal. Garcia-Austt[36] first suggested that the various components of the visual evoked potential might vary independently

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[34] H. Davis, "Enhancement of Evoked Cortical Potentials in Humans Related to a Task Requiring Decision", in Science, Vol. 145, 1964, pp. 182-183.

[35] E. Donchin and D.B. Lindsley, op. cit.

[36] E. Garcia-Austt, J. Bogacz, and A. Vanzulli, op.cit.

of each other with changes in stimulus and response conditions. Wilkinson and Morlock[37] reported such specific amplitude changes in peaks occurring at 50, 90, 260, and 350 to 450 millisecond latencies in "response" as opposed to "no response" conditions. No changes were reported with fast reactions as opposed to slow. Bostock and Jarvis[38] nevertheless claimed that reaction speed related "very strongly" to the amplitude and latency of a negative peak around 250 msec latency. Karlin *et.al.*[39] agreed and disagreed with both reports. They said that trials with a faster reaction time do show changes in specific peaks, but peaks different from those mentioned by Bostock. Similarly, trials in a choice task situation showed enhanced deflections over a simple task, but again at different latencies than Wilkinson. They finally added that a new condition, withholding a response, correlated with enhancement of a late positive peak at 300 msec relative to passively watching the stimulus or responding after a choice.

No mention has so far been made of any relation between the latency of evoked potential peaks and either attention or reaction speed. References to such a possible relation are few. Haider *et.al.*[40] reported fluctuations in the latency of prominent peaks with fluctuations in vigilance, lowered efficiency being associated with longer latencies. In this case, level of

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[37] R.T. Wilkinson and H.C. Morlock, *op.cit.*

[38] H. Bostock and M.J. Jarvis, "Changes in the Form of the Cerebral Evoked Response Related to the Speed of Simple Reaction Time", in *Electroenceph. Clin. Neurophysiol.*, Vol. 29, 1970, pp. 137-145.

[39] L. Karlin, M.J. Martz, and A.M. Mordkoff, *op.cit.*

[40] M. Haider *et.al.*, "Cortical Evoked Potentials During Visual Vigilance Task Performance", p. 714.

efficiency was indexed upon precision of performance in a discrimination task over a long experimental session. Many of the researchers already cited have tried to correlate reaction time and peak latencies, but in only one case have they succeeded in finding any consistent relationship: Bostock and Jarvis[41] claim to have found the latency of a positive-negative wave around 250 msec to be "strongly" related to reaction speed. The paucity of consistent findings implies, however, that peak latencies are probably not so closely related to arousal and attention as are peak amplitudes.

There remains, obviously, much more work to be done in the area of arousal, attention, reaction times, and their influences on evoked potential waveform. The majority of published literature seems to agree that there is some link between heightened arousal or attention or both, and larger amplitude of reliable evoked potential peaks. The precise relation, however, remains vague. With relation to reaction speed and attentional indicators in the evoked potential, little sign of consensus can be seen. A more fruitful area of investigation should be mentioned, however: that of relating reaction speed to alpha wave phase at the time of the stimulus. Calloway and Yeager[42] as well as Dustman and Beck[43] report a consistent relationship between reaction time and alpha phase at the arrival of the stimulus at the

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[41] H. Bostock and M.J. Jarvis, op. cit.

[42] E. Calloway and C.L. Yeager, "Relationship Between Reaction Time and Electroencephalographic Alpha Phase", in Science, Vol. 132, 1960, pp.1765-1766.

[43] R.E. Dustman and E.C. Beck, "Phase of Alpha Brain Waves, Reaction Time, and Visually Evoked Potentials", in Electroenceph. Clin. Neurophysiol., Vol. 18, 1965, pp. 433-440.

cortex. That is, the surface positive phase is associated with the slowest reactions, and the surface negative phase with the fastest reactions. These findings imply at least that reaction time is a reflection of the normal and almost instantaneous fluctuations in cortical activity. Whether it is more than that remains to be determined.

The present study makes use of the published literature on attention in a general way, in choosing appropriate controls and in interpreting certain results. Specifically, it was desired to obtain evoked potentials of comparable overall amplitudes under different conditions so as to be able to better make specific comparisons between individual peaks. Care was therefore taken to assure a constant level of general arousal, by keeping each experimental trial as short as possible, and a constant level of specific attention, by intermixing the different response conditions. Differences between fast and slow reactions were examined in the statistical analysis.

4. Intraindividual vs. Interindividual Variability

The effects of intraindividual variations in arousal on the waveform of the visual evoked potential have been discussed, and it is all too clear that these effects are neither well-defined nor well-understood. Yet the very difficulty of demonstrating marked changes in the evoked potential with changes in attentional or arousal level indicates that these changes are minute relative to the overall consistency of form in the evoked potential of a particular individual, and that they tend to be lost in the large variations between individuals. Wilkinson has commented on this notable intraindividual constancy as contrasted to the great variations in waveform encountered across different subjects.

> "The shape of the response varies, among other things, from subject to subject, from one sense modality to another, and from one position of the scalp to another. Of these the largest source variation is subjects, but within a subject from one experimental session to the next the shape of the evoked potential is remarkably consistent, provided the sensory mode and the electrode placement are kept the same."[44]

With these observations in mind, Perry and Childers[45] suggest that the same subject should serve as his own control in an experimental situation. It is this theory which underlies the choice of an ipsative study in the present case.

5. Rationale for the Experiments

It is likely, on both logical grounds and on the basis of experiments already cited (Ertl, Gilden et.al.), that the cortex gives rise to a certain amount of nonrandom activity prior to and immediately following a voluntary act. Placed in the context of a reaction paradigm, where sensory input to the cortex serves as a signal to motor response, the problem of detecting such activity becomes one of placing appropriate controls upon the more complex process so as to be able to sort out its individual elements and to examine them both separately and in their interactions with one another. This goal is elusive indeed, because the interaction itself

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[44] R.T. Wilkinson, "Evoked Response and Reaction Time", in Acta Psychologica, Vol. 27, 1967, p..236.

[45] N.W. Perry, Jr. and D.G. Childers, The Human Visual Evoked Response: Method and Theory, Springfield, Illinois, Charles C. Thomas, 1969, p. 9.

may significantly change each of the interacting elements: the whole is not necessarily the sum of the parts. Nevertheless, the present experiments were designed to examine a limited number of the variables involved in the reaction paradigm, each in as pure a state as possible, so as to gain some insight into the nature of their form and their interactions.

Though independently conceived and carried out, a preliminary pilot study involving nine young adults turned out to be similar in conception to the experiments reported by Vaughan _et.al._[46] Summated records of evoked potentials under two response conditions, and the result of subtracting these curves, were obtained for all nine subjects. In no case did the results resemble those published by Vaughan _et.al._ These results are not, however, reported in detail here, since they were inconclusive due to several technical problems and, in any case, fell to the same criticisms as those already cited in relation to Vaughan _et.al._

The experience gained from these failures proved valuable, nonetheless, in designing the final experimental procedure reported in the next chapter. Since the normal variance in form of the evoked potential, and perhaps also the motor potential, across individuals appeared more to obscure than to bring out the reliable elements in the recorded cortical activity, it was decided to conduct an ipsative study. Many records were obtained from one individual over a period of several days, and since the general form of the evoked potential proved to be reliable over time, these results

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[46] H.G. Vaughan, L.D. Costa, L. Gilden, and H. Schimmel, _op.cit._

could be combined to improve the signal-to-noise ratio of the records and provide more meaningful information. Another advantage of this technique, noted particularly by Wilkinson and Morlock[47], was that it reduced the confounding effects of fatigue and habituation, which quickly become apparent in long experimental sessions involving boring tasks. A check on the reliability of the evoked potential over time was introduced in the statistical analysis by blocking evoked potential records by trial number, that is, by position in time.

Much valuable information had been lost from the subtracted curves in the pilot study because of a consistently large difference in the amplitude of evoked potential peaks under no-response and response conditions, due most probably to differences in the level of arousal or attention. It was therefore decided to place more stringent controls upon these variables by having the different response conditions intermixed within the same block of stimuli. The attention level of the subject would then be essentially the same in records obtained across conditions. In addition, each experimental series was kept as short as possible, to insure a generally constant level of arousal, while yielding reliable summations of cortical activity under each condition.

A rather wide distribution of reaction times was another possibly important variable.. Thus the final statistical analysis of results includes one analysis of variance in which the evoked potential records are blocked

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[47] R.T. Wilkinson and H.C. Morlock, op.cit.

according to whether the reaction-time mode for each trial was longer or shorter than the median of all the modes. In this way the reaction-time distribution was made more leptokurtic, more closely approximating the conditions of Ertl's and Gilden's experiments, where EEG records were aligned for summation according to the moment of onset of the motor reaction.

Having thus introduced controls on the variables of subject variability, fatigue, arousal, and reaction time, it was decided that two final changes in design might prove relevant. A third channel of EEG was introduced at the C_z (vertex) location, in order to more adequately cover the motor area and to compare effects in the three different locations across it. Finally, Gilden et.al. having reported observing a more marked motor potential in conjunction with foot movement[48], it was decided to introduce a second type of response--foot reaction to the stimulus--bringing to three the number of conditions under which the evoked potential was to be recorded and examined.

Out of the review of evoked potential literature to date, and the experience gained from a pilot study, grew the design of the experiments reported in this thesis. In particular, they were intended to support or to refute the following set of null hypotheses:

1) There are no statistically significant task-related differences in the latency or amplitude of reliable peaks of the visual evoked potential obtained under three different response conditions:

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[48] L. Gilden, H.G. Vaughan Jr., and L.D. Costa, op.cit., p. 437.

2) There are no statistically significant differences in the latency or amplitude of reliable peaks of the visual evoked potential obtained from three different locations over the motor cortex;

3) There are no statistically significant differences related to the speed of reactions in the series;

4) There are no statistically significant differences related to the specific trial, or position in time, from which a particular evoked potential was obtained.

CHAPTER II

EXPERIMENTAL DESIGN

The theoretical and practical considerations underlying the design of the present experiments have been elaborated in Chapter I. The present chapter describes in more detail the experimental set-up and methods of data analysis.

1. Subject and Method

The subject for the series of experiments was a 27-year-old male who had not previously been familiar with evoked potential studies. His EEG was derived from three pairs of bipolar scalp electrodes placed over the motor cortex at C_3, C_z, and C_4 according to the international convention, and a ground electrode was placed on his left ear. The ongoing EEG was amplified by a Nihon-Kohden electroencephalograph (gain set 9x6db) and recorded on three channels of an FM tape recorder (Vetter Model A), to be later replayed for analysis. Photic stimuli of ten microsecond duration and 94,000 candlepower intensity at the source were delivered by a Grass PS-2 photostimulator placed thirty-four inches from the subject's eyes. The stimuli were recorded on an additional three channels of the tape recorder, each channel later serving as the triggering device for computer summation of EEG under one of the three conditions. A pushbutton activated by the subject's right index finger, and a pedal activated by the right foot, recorded the reaction times on the final two channels of the tape.

The subject sat in a chair with his eyes open, looking at a spot ten inches to the right of the light. After ten minutes' adaptation to darkness, a series of 150 stimuli was delivered at random intervals, approximately one every two to three seconds. The subject responded to these as follows: first flash--no response, second flash--finger response, third flash--foot response, fourth flash--no response, fifth flash--finger response, etc. The subject was left responsible for maintaining the proper order of response modalities, though the experimenter, in an adjacent room, constantly monitored both EEG and responses to be sure that no consistent errors occurred. The final computer analysis showed that no more than eight per cent of the responses were erroneous in any one trial. After a period of rest, and adaptation to darkness if necessary, the procedure was repeated. Ten such trials were carried out during two non-consecutive days. Four blocks of fifty passes with no light were interspersed among the experimental trials to control for background noise and assure that the ongoing cortical activity not evoked by photic stimulation or muscular activity was indeed random. In the final three experimental trials, the order of the foot and finger reactions was reversed, as a control on interaction effects. Before the first trial, the procedure was explained to the subject, and he was instructed to pay attention to the light and to respond as quickly as possible upon seeing the flash, in the appropriate mode. A few sample stimuli quickly acquainted him with the flashing light, the finger button, and the foot pedal.

2. Analysis of Data

The data recorded on magnetic tape during the ten experimental trials and four noise control trials was first filtered (Krohn-Hite Model 3550 filter) on a three to thirty Hertz band pass, with attenuation slope of 24 db/octave, in order to minimize the confounding effects of muscular and on-line noise.

It then passed via an AX08 lab periphery into a DEC PDP-8I digital computer. There, an averaging program permitted digitizing the data into 250 components distributed over a 500 millisecond period following the trigger pulses, averaging of data from sequential sweeps, and recording of reaction times where appropriate. The pulses triggering the averaging device were produced by a Datapulse 101 pulse generator. Those marking reaction latencies came from a Hewlett-Packard 3300A function generator with 3302A trigger/phase lock plug-in. The evoked potentials obtained by summation of digitized data from fifty sweeps for each of the three conditions and ten trials, plus four noise controls,were stored on DECtape and punched on paper tape used for all subsequent additions and subtractions of data. Data from each of the three scalp locations was always treated separately, giving a total of ninety separate evoked potentials used for analysis, plus twelve noise control series examined.

Even after summation of a fairly large number of sweeps, in any evoked potential study there still remains a decision problem as to which peaks are truly significant. In the present case this problem was dealt with as follows: nine "group" evoked potentials were obtained by summating all data corresponding to a particular location and condition, across the ten trials. This gave evoked potentials of 500 sweeps and relatively more prominent peaks. From these, nine peaks (5 positive, 4 negative) were chosen as being the most reliable across conditions and locations. Then, significant peaks of the individual (50-sweep) evoked potentials were defined as being those whose latency lay closest (usually within ±15 msec) to those of the corresponding "group" peaks. Amplitude and latency coordinates of the peaks thus defined in each of the ninety individual evoked potential records provided the data used in the statistical analyses.

A study of evoked-potential reliability was performed to assure consistency of recorded activity over time, and to ascertain the validity of any conclusions drawn from the analyses of variance. Evoked potential curves, matched for location and response condition, were randomly paired by computer and correlated for peak amplitudes and peak latencies. For the purposes of reporting reliability, ten of the 45 possible pairs under each condition and location have been randomly chosen, and their amplitude and latency correlation coefficients recorded in Appendix 1. These coefficients generally exceed 0.90 for amplitude, and range from 0.97 to 0.99 for latency. A global measure of reliability in curve form was thus obtained. In addition, the separate peaks were subjected to analysis across all conditions, locations and trials. The mean and standard deviation of amplitude and latency were calculated for all nine peaks, and are reported in Appendix 2.

The digitized data was subjected to three separate analyses of variance: 1) a two-way analysis (condition vs. location, with ten replications) with no blocking; 2) a three-way analysis with data blocked according to trial number(i.e. position in time); and 3)a three-way analysis with data blocked according to speed of reaction times ("fast" or "slow") within each trial. The Scheffé test was used to locate precisely the significant differences where a main factor having more than two levels was concerned. The results of these procedures will be recorded and discussed in the next chapter.

As a final step, in order to get a global picture of the elements distinguishing evoked potentials under the various response conditions, a series of subtractions was performed, similar to those reported by Vaughan *et.al.*[1] The "group" evoked potentials from the no-response condition were subtracted from those of the foot response and the finger response conditions, using the same averaging program and the PDP-8I computer mentioned previously. The resulting "difference" curves were used in conjunction with the statistical analyses for interpreting certain results.

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[1] H.G.Vaughan, L.D.Costa, L.Gilden, and H.Schimmel, *op.cit.*

CHAPTER III

RESULTS AND DISCUSSION

The two types of analysis applied in the present design complement each other, and point toward compatible conclusions. The subtraction of curves gives a more global and intuitive picture of differences between response conditions. The statistical analyses of amplitude and latency coordinates of the nine reliable evoked potential elements reveal significant differences in these coordinates due to three different main effects: response condition, location, and speed of reaction. A summary of these differences, and their level of significance, is found in Tables I and II. More detailed results of the analyses are included in Appendix 3.

1. Subtraction of Curves

Subtraction of the "group" evoked potentials (500 sweeps) under the no-response condition from those obtained when a motor response was required yielded a curve containing between three and eleven apparently reliable positive and negative elements. No formal reliability study was made in this case, due to insufficient data, and to the fact that the reliability of the curves used in the subtraction had already been established. Furthermore, the subtraction was intended only to give a general picture of the pattern of differences--that which subsequently aided interpretation of the more precise statistical analyses. Figures 1 and 2 show examples of two subtractions. Most noticeable in the "difference" curves are three elements: 1) a positive peak of latency around 100 msec; 2) a negative shift reaching

Table I.

Summary of Significant Differences in Peak Latencies
Revealed in Three Analyses of Variance

Peak	Mean Latency(msec)	ANOVA #	Latency Differences Source	Significance
P_1	37	I	task	.05
		II	task x location interaction	.05
		III	task	.05
N_1	76	I	task	.001
		II	task	.01
		III	task	.01
			location x speed interaction	.001
P_2	120	I	task	.01
		II	task	.01
		III	---	---
N_2	164	I	location	.001
		II	location	.001
		III	location	.01
P_3	199	I	task	.05
		II	---	---
		III	---	---
N_3	212	I	task	.01
			location	.01
		II	---	---
		III	task x location interaction	.01
P_4	240	I	task	.001
		II	task	.01
			location	.05
		III	task	.05
			speed	.05
N_4	338	I	task	.001
		II	task	.001
		III	speed	.05
			task x speed interaction	.01
P_5	440	I	task	.001
		II	task	.001
		III	speed	.001

Table II.

Summary of Significant Differences in Peak Amplitudes
Revealed in Three Analyses of Variance

Peak	Mean Amplitude	ANOVA #	Amplitude Differences Source	Significance
P_1	7	I	---	---
		II	---	---
		III	task x speed interaction	.001
N_1	-7	I	---	---
		II	location	.05
		III	---	---
P_2	11	I	location	.001
		II	location	.001
		III	location	.05
			speed	.01
N_2	-28	I	task	.001
			location	.001
		II	task	.01
			location	.001
		III	location	.05
			speed	.01
P_3	10	I	---	---
		II	---	---
		III	task x speed interaction	.05
N_3	5	I	location	.01
		II	---	---
		III	task x speed interaction	.05
P_4	32	I	location	.001
		II	location	.001
			task	.01
		III	location	.01
N_4	-30	I	location	.001
		II	location	.001
		III	location	.05
			speed	.05
P_5	24	I	location	.01
		II	location	.01
		III	speed	.05

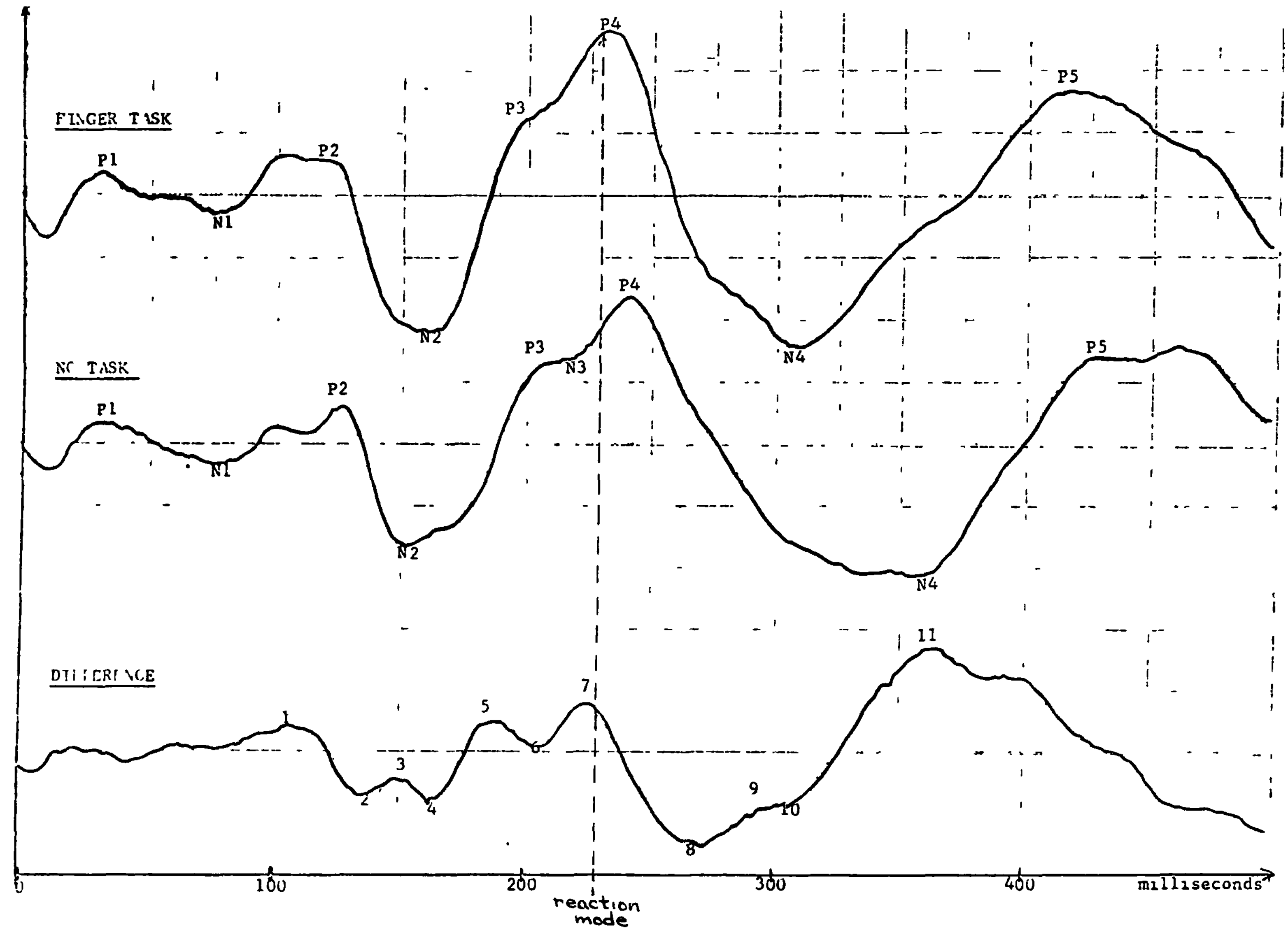

Figure 1. Evoked Potential Subtraction: Sum of EEG activity following stimulation over 500 passes with no task subtracted from sum over 500 passes with finger task (Left motor cortex location, C_3).

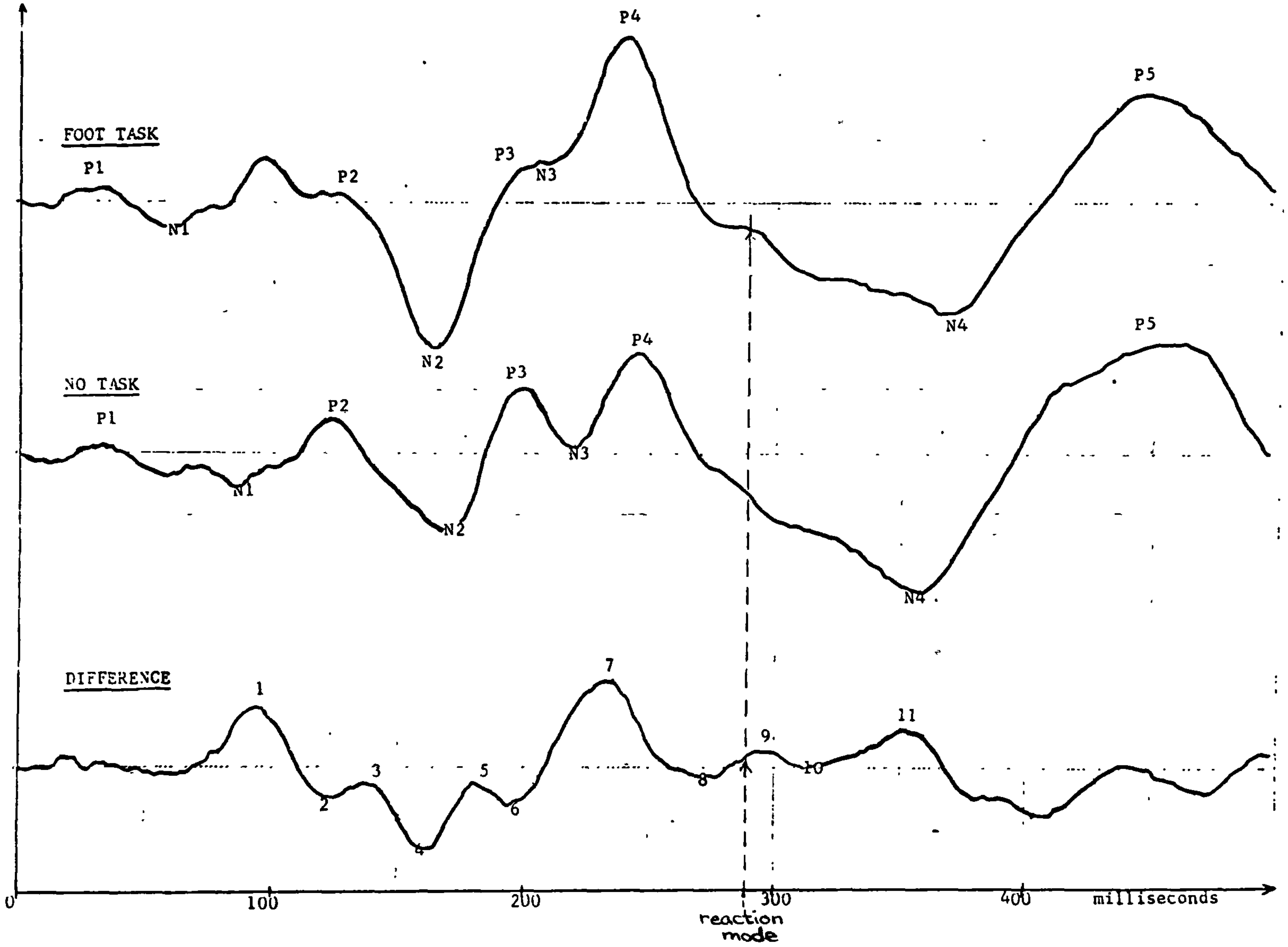

Figure 2. Evoked Potential Subtraction: Sum of EEG activity following stimulation over 500 passes with no task subtracted from sum over 500 passes with foot task (Center or vertex location, C_z).

its maximum close to the 160 msec point; and 3) a second positive peak of latency around 230 msec. Although the mean latency of reaction times for the finger reaction was 229 msec, and for the foot was 288 msec, the above pattern occurs with the same latency under the two conditions.

2. Effects of Different Response Conditions

In this ipsative study, responding to the light flash with a finger movement, with a foot movement, or not responding at all, resulted in differential effects on the latency of reliable evoked potential peaks. All peaks except one (N_2) were significantly affected in this way. The pattern of effects, however, is most interesting. In the early peaks, P_1, N_1, and P_2, the foot response condition is associated with the shortest latencies. At N_2 there are no significant differences across conditions, but at P_3 and every peak thereafter, it is the finger response condition which corresponds, with progressively greater significance, to the shortest latencies. This pattern is evident in Table III.

From the table it is also clear that the effect of different response conditions on peak amplitudes is significant only at N_2 and P_4. This fact is meaningful in two respects. First, the fact that most evoked potential elements show no change in amplitude whether the subject made a motor response or not, indicates that the attempt to control attention level (and therefore amplitude of the evoked potential) by mixing response and no-response conditions in the same block of stimuli, was successful. Because of this fact, a second inference can be drawn with much confidence. The amplitude of N_2 in particular, and also P_4, are greater--that is, N_2 is

Table III.

Summary of Significant Differences in Peak Latency and Amplitude due to the Main Effect of Response Condition*

Peak	Mean lat/amp.	ANOVA #	Latency Differences	Amplitude Differences
P_1		I	Foot < NoT+Fin (.05)	---
lat.	39	II	---	---
amp.	7	III	Foot< NoT(.05); Foot< Fin(.05)	---
N_1		I	Fin < NoT(.05); Foot< NoT(.01)	---
lat.	76	II	Foot< NoT(.05)	---
amp.	-7	III	Fin< NoT(.01); Foot< NoT(.01); Foot< Fin(.05)	---
P_2		I	Fin < NoT(.05); Foot < NoT(.05)	---
lat.	120	II	Fin< NoT(.05); Foot< NoT(.05)	---
amp.	11	III	---	
N_2		I	---	Fin> NoT(.05); Foot> NoT(.05)
lat.	164	II	---	Fin > NoT(.05)
amp.	-28	III	---	---
P_3		I	Fin < NoT(.05)	---
lat.	199	II	---	---
amp.	10	III	---	---
N_3		I	Fin < NoT(.05)	---
lat.	212	II	---	---
amp.	5	III	---	---
P_4		I	Fin < NoT(.01); Fin < Foot(.05)	---
lat.	240	II	Fin < NoT(.01)	Fin > NoT(.05); Foot > NoT(.01)
amp.	32	III	Fin < NoT(.05)	---
N_4		I	Fin < NoT(.01); Fin < Foot(.01)	---
lat.	338	II	Fin< NoT(.01); Fin< Foot(.01)	---
amp.	-30	III	---	---
P_5		I	Fin < NoT(.01); Fin < Foot(.01)	---
lat.	440	II	Fin<NoT(.01); Fin<Foot(.01)	---
amp.	24	III	---	---

*Key: Fin - finger response; Foot - foot response; NoT - no response more negative and P_4 more positive--in the two response conditions than they are when no response is required. It is likely, then, that these changes in amplitude are specifically related to the motor response conditions. Furthermore, the mean latencies of N_2 (164 msec) and P_4 (240msec) correspond almost precisely to those of the negative shift and the following positive peak already noted on the subtracted curves. Thus it would seem logical to assume that the pattern of differences seen in this area of the "difference"curves can be accepted as reflecting statistically significant differences in the evoked potentials under two different conditions.

From the graphical evidence (Figs.1,2) the negativity in the region of N_2 has a rather gradual onset, casting some doubt on its relation to the abrupt negative shift preceding a motor response, reported by Gilden et.al.[1] and Ertl[2]. However, it must be remembered that their "motor potential" was discovered by averaging EEG's aligned so as to make the time of overt motor reaction coincide on each sweep. Here, on the contrary, the reaction times are rather widely distributed, since alignment was done on the basis of stimulus point. Thus the gradual onset of negativity is not in itself a reason to reject the possibility of such a relationship.

Relating the negative shift to reaction time raises additional interesting possibilities. The point of maximum negativity on the difference curves, falling very close to N_2 (mean latency 164 msec), lies 65 msec prior to the mean of the reaction modes under the finger response condition (129 msec), and 124 msec from that of the foot response condition (288 msec). These delays are consistent with the 50 to 150 msec separation between

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[1] L.Gilden, H.G.Vaughan Jr., and L.D.Costa, op.cit.

[2] John Ertl, op.cit.

abrupt negative shift and overt motor response reported by Gilden *et.al.*[3] If they are somewhat longer than those mentioned by Vaughan *et.al.*[4] (30 to 40 msec for finger; 60 to 80 msec for foot), the difference may be due both to confounding factors in their experiment which were better controlled here, and to the fact that they measured reaction time to the onset of EMG potential, whereas in the present design an overt movement was necessary to complete the circuit recording reaction time. The point of maximum negativity, rather than the onset of the negative shift, is chosen as the best correlate of the previously-reported abrupt shift because of the wide spread of reaction times and the fact that the attempt here has been to relate it to a mean of reaction-time modes over ten trials. It is not surprising that the maximum negativity coincide for finger and foot reactions since afferent transmission and integration times would logically be the same for both, a difference in reaction time being incurred by differing efferent transmission times to the extremities. If these arguments are accepted, it seems reasonable to admit the possibility that the significant N_2 enhancement may be due to the specific effect of a "motor potential" similar to that reported by Gilden *et.al.* and Ertl under different conditions. Additional research is needed to definitively determine whether the pre-reaction enhancement of N_2 in the visual evoked potential of the present subject is due to the specific effect of a "motor potential" or whether it represents a more general excitatory state, as Karlin *et.al.*[5] would have it.

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[3] L.Gilden, H.G.Vaughan Jr., and L.D.Costa, *op.cit.*, p.434.

[4] H.G.Vaughan, L.D.Costa, L.Gilden, and H.Schimmel, *op.cit.*, p.180.

[5] L.Karlin, M.J.Martz, S.E.Brauth, and A.M.Mordkoff, *op.cit.*

Statistically, the present data shows a much more localized negative shift than does that presented by the latter group. The experimental design was similar to theirs in that the subject was responsible for responding or for withholding his response, though in the present design no instantaneous decision was required on the basis of randomly assorted signals. Still, general attention and "readiness" have been shown to have been well controlled, and therefore the more specific "motor potential" interpretation is favored in this case.

The enhancement of P_4 during the reaction conditions is an anomaly requiring further research. Previously, the positive shifts reported occurred subsequent to the reaction and were therefore interpreted as afferent feedback from the reaction. In the present case, however, a significant positive enhancement occurs only at P_4, nearly coincident with the finger reaction mean, and well before the foot reaction mean. It may be due in this case to a simple "rebound effect" of many neurons recovering after firing simultaneously. If so, it too would point toward the specific effect of a sudden and widespread activation as the best explanation for the preceding negative shift at N_2.

A final point may be made with reference to this enhancement of certain peaks during the motor response conditions. That the motor potential should appear as an enhancement of specific peaks, rather than as a more independent factor superimposed upon the normal visual evoked potential form, is an intriguing coincidence. Bates has suggested that movement may be initiated only at certain points of the alpha cycle[6]. A review of the

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[6] J.A.V.Bates, op.cit., p. 256.

literature has shown reaction speed to be related to alpha wave phase. Could the present finding be related to these observations? Is an individual limited in his ability to time voluntary acts by the natural rhythmic activity of his cortex? This field is certainly ripe for some fruitful investigation.

3. Effects of Different Cortical Locations

Table III contains a summary of the differences in peak latencies and amplitudes related through statistical analysis to differences in location of the scalp electrodes from which recordings were made. Across all these analyses, only N_2 shows significant differences in latency depending upon the location of cortical recording. This is indeed remarkable, since the analysis of task differences has revealed that N_2 is most probably involved in some way with motor activation. The location-related latency differences may possibly give a clue as to the pattern of that activation. In particular, all three analyses emphasize that the latency of N_2 is shorter at the left location than at the right, and in turn shorter at the right than at the center. The left location being over the part of the motor cortex contralateral to the activated hand or foot, activation may logically be initiated there, then pass to the right hemisphere via the corpus callosum, and thence upward toward the vertex. This interpretation is consistent with Cernacek's contralateral motor irradiation hypothesis, though it goes somewhat further by speculating that facilitation spreads to the vertex area. Further inquiry into the problem of an activation pattern may well prove fruitful in understanding the nature of cortical activity.

The differences in peak amplitudes according to location are more

Table IV.

Summary of Significant Differences in Peak Latency and Amplitude due to the Main Effect of Cortical Location*

Peak	Mean lat/amp.	ANOVA #	Latency Differences	Amplitude Differences
P_1		I	---	---
lat.	39	II	---	---
amp.	7	III	---	---
N_1		I	---	---
lat.	76	II	---	C>L (.05)
amp.	-7	III	---	---
P_2		I	---	R>L (.01); R>C (.01)
lat.	120	II	---	R>L (.01); R>C (.01)
amp.	11	III	---	R>L+C (.01)
N_2		I	L<C (.01)	R>L (.01); R>C (.01)
lat.	164	II	L<C(.01); L<R(.05); R<C(.05)	R>L (.01); R>C (.01)
amp.	-28	III	L<C(.01); L<R(.01); R<C(.01)	R>L (.05); R>C (.05)
P_3		I	---	---
lat.	199	II	---	---
amp.	10	III	---	---
N_3		I	R<C (.05)	C>L (.05)
lat.	212	II	---	---
amp.	5	III	---	---
P_4		I	---	R>L (.01); R>C (.01)
lat.	240	II	L<C (.05)	R>L (.01); R>C (.01)
amp.	32	III	---	R>L (.01); R>C (.01)
N_4		I	---	R>L (.01); R>C (.01)
lat.	338	II	---	R>L (.01); R>C (.01)
amp.	-30	III	---	R>L (.05); R>C (,05)
P_5		I	---	R>L (.05); R>C (.05)
lat.	440	II	---	R>L (.05); R>C (.05)
amp.	24	III	---	---

*Key: L - left location; C - center, or vertex, location; R - right location consistent and more marked. In general, the right hemisphere gave an evoked potential with greater variance and, accordingly, larger peak amplitudes than either the left or the vertex locations, which were not usually significantly different from each other. This difference likely reflects the position of the photic stimulus in the subject's visual field, the most intense stimulation going to the right hemisphere. Two additional factors may have contributed as well to the greater variance on the right: the fact that the stimulus was non-verbal and the fact that the subject was likely of above-average intelligence, being a Ph.D. candidate at the time of the experiments. Both the stimulus type and the level of intelligence have already been mentioned as associated with larger amplitude responses in the right hemisphere. Nevertheless, the significance does not carry through all the peaks. It is found at P_2 and N_2, then again at P_4 and later peaks. Again, these are precisely the areas most closely related to motor activity. Why one hemisphere should be more highly sensitized to such activity or, on the contrary, whether it does have any special relation to the motor tasks are questions open to further investigation. The tendency for higher amplitudes to occur at the center location at N_1 and N_3 also needs further confirmation or rejection.

4. Effects of Reaction Speed

The analysis of effects of reaction speed on latency and amplitude of the evoked potential peaks gives somewhat inconclusive results, though the differences due to the main effect are consistently in the same direction. In particular, the latency of the late peaks P_4, N_4, and P_5 is significantly shorter when the reaction is classified as "fast" than when it is "slow". If it is assumed that a fast reaction reflects a high level of arousal at the time of the

Table V.

Summary of Significant Differences in Peak Latency and Amplitude due to the Main Effect of Reaction Speed

Peak	Mean lat./ amp.	Latency Differences	Amplitude Differences
P_1	lat. 39 amp. 7	---	---
N_1	lat. 76 amp. -7	---	---
P_2	lat. 120 amp. 11	---	Fast < Slow (.01)
N_2	lat. 164 amp. -28	---	Fast < Slow (.01)
P_3	lat. 199 amp. 10	---	---
N_3	lat. 212 amp. 5	---	---
P_4	lat. 240 amp. 32	Fast < Slow (.05)	---
N_4	lat. 338 amp. -30	Fast < Slow (.05)	Fast < Slow (.05)
P_5	lat. 440 amp. 24	Fast < Slow (.001)	Fast < Slow (.05)

stimulus, this finding is in accord with that of Haider et.al.[7], who related level of vigilance to latency of evoked potential peaks and found similar results. As seen in Chapter I, however, other authors disagree, finding no correlation between reaction time and peak latencies. The question deserves further study, and especially the aspect of the late appearance of significance in latency differences. This corrollary could perhaps find some elucidation in a study of the post-reaction afferent feedback mechanism. The present design was not conceived to deal with this particular problem, and the method of distinguishing "fast" from "slow" was imperfect due to technical requirements: the two reaction conditions being intermixed, reaction times from each trial had to be classified together as "fast" or "slow" even though they were in two cases of opposite classification. The distinction is therefore somewhat blurred in this case, and needs further study.

Another phenomenon which should receive further attention is the relationship between reaction speed and amplitude of the evoked potential peaks. It is apparent from Table V that in the present design the amplitude of the peaks in evoked potentials associated with fast reactions is consistently smaller than, or equal to, the amplitudes of those associated with slow reactions. On the contrary, the published literature generally asserts the opposite--that fast reactions are associated with enhanced positive and negative peaks. Were it not for a widespread consensus to this effect,the present results could be logically explained on the grounds that

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[7] M. Haider, P. Spong, and D.B. Lindsley, op.cit.

a normal aroused EEG is characterized by low amplitude, high frequency activity and that this type of activity, summated over many trials, might yield an evoked potential of significantly smaller amplitude variance than one occurring under under more relaxed conditions. Another possibility is that the decision as to response modality served as a distraction to the subject, giving results similar to those of Satterfield's first experiments.[8] Or, this finding may reveal a unique characteristic of the present subject, not commonly found in a larger population sample. In any case, this problem should receive further study.

5. Effects of Position in Time

The statistical analysis with blocking by trial number--that is, position in time--of the experimental series, revealed no significant trial-related differences in amplitude or latency of evoked potential peaks. This finding is in accord with that generally reported in the published literature: the evoked potential of a particular person has a characteristic form which remains quite stable through time. It provides strong support for the logic underlying this ipsative study, that some of the confusion introduced into evoked potential studies by wide interindividual differences can be avoided by taking repeated measures upon the same person over time. An ipsative study does not, of course, guarantee generalizability of results to large populations, but it may help to clarify the possible utility of specific methods and theories to a still very young field before the more difficult job of generalization should be attempted.

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[8] J.H. Satterfield and D. Cheatum, op. cit.

SUMMARY AND CONCLUSIONS

As a first step toward understanding the significance of the electrical activity of the cortex in human behavior, it is essential to confront it in its most simple form: as the basic stimulus-response paradigm. At the present time, however, there is much controversy in this field with respect to the effects of motor activity on the sensory evoked potential, and little insight into the differences in electrical activity in different parts of the brain. For these reasons, the present project was conceived and carried out.

An ipsative study, involving only one subject but taking measures during ten trials over a period of several days, was considered most appropriate for detecting reliable, time-locked, but elusive factors obscured by ongoing random EEG activity. Evoked potential measures from three different areas of the motor cortex were obtained under three different response conditions, and statistically analyzed for the main effects of response condition, location, speed of reaction, and position in time. These experiments led to the rejection of three out of the four preliminary null hypotheses. Significant differences were found in the latency and amplitude of reliable peaks of the visual evoked potential due to response modality, location of recording electrodes, and speed of reaction, but not due to position of the experimental trial in time.

The effect of response modality on latency of the peaks followed a pattern, the shortest latencies being associated with the foot response condition in the early peaks, but with the finger response condition in the later peaks. The amplitude of only two peaks was affected, N_2 (164 msec) very significantly, and P_4 (240 msec) to some extent, both finger and foot response conditions being associated with larger amplitudes than the no-response condition. These results suggest that the negative enhancement of N_2 may be due to the simultaneous firing of many neurons, a sudden activation of the corticospinal tracts, leading to execution of a motor response. The positive enhancement of P_4 may result from a "rebound" or recovery effect.

The effect of location over the motor cortex upon peak latencies was found to be significant primarily at N_2. This being the peak most affected in amplitude by motor response, an activation pattern within the cortex is hypothesized. Since only a few previous reports hint at such a pattern, the possibility deserves further attention. Locational differences in peak amplitudes are consistent and significant, the right hemisphere showing greater variance than either the left or center locations, as a result of stimulus placement and normal hemispheric differences in activity level.

The effects of reaction speed are less clear in their interpretation. The latency of three late peaks is shorter with faster reaction speed. Though probably related to activation level, the reason for the late appearance of the effect is not clear. The amplitude of all peaks is the same or smaller with fast reactions than with slow, contrary to most published data. Whether this is simply an individual characteristic of the subject, or whether due to a distracting task, should be further investigated.

The effect of position of the experimental series in time was in no case significant. This fact provides confirmation of the utility of an ipsative study

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APPENDIX 1

SAMPLE CORRELATION COEFFICIENTS OF LATENCY AND AMPLITUDE COORDINATES FOR SIGNIFICANT PEAKS:

AN ESTIMATE OF RELIABILITY OVER TIME OF EVOKED POTENTIAL WAVEFORM*

*Key: NOT - no-response condition; FIN - finger response condition;
FOO - foot response condition.

L - left location; C - center, or vertex, location;
R - right location.

1 through 10 - trial number.

Correlated Pair **Amplitude Reliability** **Latency Reliability**

```
NOT  L   1 AND NOT  L   8 CORR, AMP.   0,853 CORR, LAT.    0.992
NOT  L   9 AND NOT  L   1 CORR, AMP.   0,929 CORR, LAT.    0.996
NOT  L   4 AND NOT  L   9 CORR, AMP.   0,936 CORR, LAT.    0.994
NOT  L   8 AND NOT  L   1 CORR, AMP.   0,853 CORR, LAT.    0.992
NOT  L   7 AND NOT  L   6 CORR, AMP.   0,784 CORR, LAT.    0.992
NOT  L   6 AND NOT  L  10 CORR, AMP.   0,904 CORR, LAT.    0.999
NOT  L  10 AND NOT  L   3 CORR, AMP.   0,936 CORR, LAT.    0.993
NOT  L   3 AND NOT  L   8 CORR, AMP.   0,953 CORR, LAT.    0.993
NOT  L   4 AND NOT  L   3 CORR, AMP.   0,932 CORR, LAT.    0.993
NOT  L  10 AND NOT  L   9 CORR, AMP.   0,927 CORR, LAT.    0.998
NOT  C   4 AND NOT  C  10 CORR, AMP.   0.926 CORR, LAT.    0.992
NOT  C   4 AND NOT  C   3 CORR, AMP.   0,853 CORR, LAT.    0.987
NOT  C  10 AND NOT  C   7 CORR, AMP.   0,822 CORR, LAT.    0.995
NOT  C   5 AND NOT  C  10 CORR. AMP.   0,942 CORR, LAT.    0.994
NOT  C   2 AND NOT  C  10 CORR, AMP.   0,895 CORR, LAT,    0.996
NOT  C   1 AND NOT  C   8 CORR, AMP.   0,934 CORR, LAT.    0.996
NOT  C   2 AND NOT  C   4 CORR, AMP.   0,955 CORR, LAT.    0.988
NOT  C   1 AND NOT  C   4 CORR, AMP.   0,915 CORR, LAT.    0.991
NOT  C   5 AND NOT  C   9 CORR. AMP.   0,906 CORR, LAT.    0.992
NOT  C   8 AND NOT  C   1 CORR, AMP.   0,934 CORR, LAT.    0.996
NOT  R   8 AND NOT  R   1 CORR, AMP.   0,965 CORR, LAT.    0.990
NOT  R   3 AND NOT  R   1 CORR, AMP.   0,955 CORR. LAT.    0.990
NOT  R   3 AND NOT  R   5 CORR, AMP.   0,947 CORR, LAT.    0.992
NOT  R   1 AND NOT  R   3 CORR, AMP.   0,955 CORR, LAT.    0.990
NOT  R   5 AND NOT  R  10 CORR, AMP.   0,939 CORR, LAT.    0.988
NOT  R   4 AND NOT  R   1 CORR, AMP.   0,969 CORR. LAT.    0.994
NOT  R   2 AND NOT  R   9 CORR, AMP.   0,983 CORR. LAT.    0.997
NOT  R   7 AND NOT  R   5 CORR, AMP.   0.929 CORR, LAT.    0.987
NOT  R   3 AND NOT  R   4 CORR, AMP.   0,900 CORR, LAT.    0.998
NOT  R   3 AND NOT  R   6 CORR, AMP.   0,950 CORR, LAT.    0.998
```

APPENDIX 1

```
FIN  L  10 AND FIN  L   4 CORR. AMP.   0.939 CORR. LAT.   0.995
FIN  L   9 AND FIN  L   6 CORR. AMP.   0.910 CORR. LAT.   0.996
FIN  L   4 AND FIN  L   5 CORR. AMP.   0.931 CORR. LAT.   0.990
FIN  L   1 AND FIN  L  10 CORR. AMP.   0.941 CORR. LAT.   0.990
FIN  L   6 AND FIN  L   9 CORR. AMP.   0.910 CORR. LAT.   0.996
FIN  L   1 AND FIN  L   9 CORR. AMP.   0.846 CORR. LAT.   0.993
FIN  L   2 AND FIN  L   1 CORR. AMP.   0.986 CORR. LAT.   0.998
FIN  L  10 AND FIN  L   9 CORR. AMP.   0.931 CORR. LAT.   0.998
FIN  L   2 AND FIN  L   9 CORR. AMP.   0.843 CORR. LAT.   0.995
FIN  C   4 AND FIN  C   3 CORR. AMP.   0.886 CORR. LAT.   0.988
FIN  C   8 AND FIN  C   3 CORR. AMP.   0.978 CORR. LAT.   0.988
FIN  C   8 AND FIN  C   3 CORR. AMP.   0.978 CORR. LAT.   0.988
FIN  C   6 AND FIN  C   8 CORR. AMP.   0.896 CORR. LAT.   0.994
FIN  C  10 AND FIN  C   6 CORR. AMP.   0.950 CORR. LAT.   0.997
FIN  C   7 AND FIN  C   3 CORR. AMP.   0.930 CORR. LAT.   0.990
FIN  C   5 AND FIN  C   7 CORR. AMP.   0.793 CORR. LAT.   0.983
FIN  C   3 AND FIN  C   8 CORR. AMP.   0.978 CORR. LAT.   0.988
FIN  R   2 AND FIN  R   7 CORR. AMP.   0.866 CORR. LAT.   0.988
FIN  R   8 AND FIN  R   9 CORR. AMP.   0.953 CORR. LAT.   0.999
FIN  R   1 AND FIN  R   9 CORR. AMP.   0.956 CORR. LAT.   0.995
FIN  R   6 AND FIN  R   9 CORR. AMP.   0.780 CORR. LAT.   0.997
FIN  R   9 AND FIN  R   2 CORR. AMP.   0.978 CORR. LAT.   0.992
FIN  R   4 AND FIN  R   3 CORR. AMP.   0.994 CORR. LAT.   0.994
FIN  R   2 AND FIN  R   5 CORR. AMP.   0.889 CORR. LAT.   0.990
FIN  R   1 AND FIN  R   2 CORR. AMP.   0.956 CORR. LAT.   0.993
FIN  R  10 AND FIN  R   7 CORR. AMP.   0.928 CORR. LAT.   0.998
FIN  R   4 AND FIN  R   9 CORR. AMP.   0.930 CORR. LAT.   0.998
FOO  L   1 AND FOO  L   9 CORR. AMP.   0.932 CORR. LAT.   0.996
FOO  L   1 AND FOO  L  10 CORR. AMP.   0.969 CORR. LAT.   0.997
FOO  L   7 AND FOO  L   4 CORR. AMP.   0.898 CORR. LAT.   0.982
FOO  L   7 AND FOO  L   3 CORR. AMP.   0.922 CORR. LAT.   0.990
FOO  L  10 AND FOO  L   4 CORR. AMP.   0.938 CORR. LAT.   0.993
FOO  L   2 AND FOO  L   4 CORR. AMP.   0.775 CORR. LAT.   0.977
FOO  L   3 AND FOO  L   1 CORR. AMP.   0.974 CORR. LAT.   0.992
FOO  L   3 AND FOO  L   7 CORR. AMP.   0.922 CORR. LAT.   0.990
FOO  L   5 AND FOO  L   4 CORR. AMP.   0.891 CORR. LAT.   0.996
FOO  L   2 AND FOO  L   5 CORR. AMP.   0.684 CORR. LAT.   0.979
FOO  C   2 AND FOO  C   4 CORR. AMP.   0.781 CORR. LAT.   0.974
FOO  C   6 AND FOO  C   4 CORR. AMP.   0.892 CORR. LAT.   0.995
FOO  C   7 AND FOO  C   4 CORR. AMP.   0.811 CORR. LAT.   0.988
FOO  C   9 AND FOO  C   3 CORR. AMP.   0.946 CORR. LAT.   0.993
FOO  C   2 AND FOO  C   9 CORR. AMP.   0.876 CORR. LAT.   0.985
FOO  C   3 AND FOO  C  10 CORR. AMP.   0.819 CORR. LAT.   0.992
FOO  C   3 AND FOO  C   6 CORR. AMP.   0.970 CORR. LAT.   0.995
FOO  C   5 AND FOO  C   3 CORR. AMP.   0.964 CORR. LAT.   0.982
FOO  R   2 AND FOO  R  10 CORR. AMP.   0.941 CORR. LAT.   0.995
FOO  R  10 AND FOO  R   4 CORR. AMP.   0.909 CORR. LAT.   0.998
FOO  R   8 AND FOO  R   4 CORR. AMP.   0.934 CORR. LAT.   0.998
FOO  R   9 AND FOO  R   8 CORR. AMP.   0.946 CORR. LAT.   0.995
FOO  R   6 AND FOO  R   1 CORR. AMP.   0.966 CORR. LAT.   0.992
FOO  R   6 AND FOO  R   8 CORR. AMP.   0.960 CORR. LAT.   0.998
FOO  R   6 AND FOO  R   1 CORR. AMP.   0.966 CORR. LAT.   0.992
FOO  R   3 AND FOO  R   2 CORR. AMP.   0.952 CORR. LAT.   0.995
FOO  R   1 AND FOO  R   7 CORR. AMP.   0.891 CORR. LAT.   0.988
FOO  R   8 AND FOO  R   9 CORR. AMP.   0.946 CORR. LAT.   0.995
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APPENDIX 2

DISPERSION OF PEAK LATENCIES AND AMPLITUDES ACROSS ALL CONDITIONS AND LOCATIONS: A LIBERAL ESTIMATE TO AID IN INTERPRETATION OF THE OVERALL RELIABILITY COEFFICIENTS WITH REFERENCE TO INDIVIDUAL PEAKS

Peak	Latency		Amplitude	
	Mean	Standard Deviation	Mean	Standard Deviation
P_1	37.3	14.0	6.6	5.1
N_1	77.6	14.5	-7.0	4.7
P_2	120.0	11.3	11.2	7.2
N_2	164.2	6.9	-27.7	11.8
P_3	198.7	6.7	9.8	8.6
N_3	212.3	9.2	5.5	8.0
P_4	240.5	7.0	31.5	13.5
N_4	338.3	26.3	-30.4	11.3
P_5	439.0	19.5	23.6	7.8

APPENDIX 3

DETAILED RESULTS OF THE ANALYSES OF VARIANCE

The following pages contain the results of three different analyses of variance, all using the same data (peak amplitude and latency coordinates), but treating it in different ways. Differences significant at a level of probability greater than 0.05 have been indicated on the tables.

The first analysis (ANOVA I in the text) uses a simple two-way design. Factor A has three levels and represents response condition. Factor B has three levels, representing cortical location. Factor C is the replication factor, with 10 elements in each of the 9 cells.

The second analysis (ANOVA II) uses a blocked design. Factor C is the blocked factor, having ten levels corresponding to the 10 experimental trials. Factors A and B are the same as before.

The third analysis (ANOVA III) introduces a new blocking factor--that of reaction time speed. This is Factor C, having two levels. Factor D is the replication factor, with five elements in each of 18 cells, while Factors A and B are again response condition and cortical location respectively. In this analysis it will be noted that interactions between main factors are frequently significant. As the Scheffé post-hoc test for significant differences revealed no consistent trends in these interactions, they were not included in the tables summarizing main effects in the text. The results are, however, available upon request from the author.

APPENDIX 3

```
 ANALYSIS OF VARIANCE SUMMARY TABLE FOR DEPENDENT VARIABLE      1
----------------------------------------------------------------                P1 latency

SOURCE                NESTING  DEGREES OF FREEDOM   SUM OF SQUARES       MEAN SQUARE    F RATIO   PROB.

                                     NUM      DEN               *SIGNIFICANT*
                                                                  *DIGITS*
                                                                  *IN SS*


A                                      2       81     0,30526667D 03 *8*   0,15263333D 03    3,2992  0,04193 task
B                                      2       81     0,31200000D 02 *8*   0,15600000D 02    0,3372  0,71477
AXB                                    4       81     0,32413333D 03 *7*   0,81033333D 02    1,7515  0,14676
C                     A,B             81              0,37474000D 04 *8*   0,46264198D 02


 ANALYSIS OF VARIANCE SUMMARY TABLE FOR DEPENDENT VARIABLE      2
----------------------------------------------------------------                P1 amplitude

SOURCE                NESTING  DEGREES OF FREEDOM   SUM OF SQUARES       MEAN SQUARE    F RATIO   PROB.

                                     NUM      DEN               *SIGNIFICANT*
                                                                  *DIGITS*
                                                                  *IN SS*


A                                      2       81     0,54155556D 02 *8*   0,27077778D 02    1,0618  0,35061
B                                      2       81     0,67222222D 02 *8*   0,33611111D 02    1,3180  0,27336
AXB                                    4       81     0,12871111D 03 *7*   0,32177778D 02    1,2618  0,29186
C                     A,B             81              0,20657000D 04 *8*   0,25502469D 02
```

```
 ANALYSIS OF VARIANCE SUMMARY TABLE FOR DEPENDENT VARIABLE      3
-----------------------------------------------------------------

SOURCE               NESTING  DEGREES OF FREEDOM  SUM OF SQUARES       MEAN SQUARE      F RATIO   PROB.

                                 NUM      DEN               *SIGNIFICANT*
                                                               *DIGITS*
                                                               *IN SS*

A                                  2       81     0,67326667D 03 *8*  0,33663333D 03    7,2143  0,00131
B                                  2       81     0,15166667D 03 *8*  0,75833333D 02    1,6252  0,20323
AXB                                4       81     0,13986667D 03 *7*  0,34966667D 02    0,7494  0,56129
C                    A,B          81              0,37796000D 04 *8*  0,46661728D 02
```

N1 latency

task

```
 ANALYSIS OF VARIANCE SUMMARY TABLE FOR DEPENDENT VARIABLE      4
-----------------------------------------------------------------

SOURCE               NESTING  DEGREES OF FREEDOM  SUM OF SQUARES       MEAN SQUARE      F RATIO   PROB.

                                 NUM      DEN               *SIGNIFICANT*
                                                               *DIGITS*
                                                               *IN SS*

A                                  2       81     0,58200000D 02 *8*  0,29100000D 02    1,2686  0,28676
B                                  2       81     0,61266667D 02 *8*  0,30633333D 02    1,3354  0,26878
AXB                                4       81     0,47333333D 02 *7*  0,11833333D 02    0,5158  0,72426
C                    A,B          81              0,18581000D 04 *8*  0,22939506D 02
```

N1 amplitude

APPENDIX 3

```
ANALYSIS OF VARIANCE SUMMARY TABLE FOR DEPENDENT VARIABLE    5                  P2 latency
-----------------------------------------------------------------

SOURCE                 NESTING  DEGREES OF FREEDOM  SUM OF SQUARES      MEAN SQUARE      F RATIO   PROB.

                                      NUM      DEN              *SIGNIFICANT*
                                                                  *DIGITS*
                                                                  *IN SS*

A                                       2       81  0,33646667D 03 *8*  0,16823333D 03    5,7270  0,00472  task
B                                       2       81  0,10980000D 03 *8*  0,54900000D 02    1,8689  0,16088
AXB                                     4       81  0,36333333D 02 *6*  0,90833333D 01    0,3092  0,87104
C                       A,B            81           0,23794000D 04 *8*  0,29375309D 02


ANALYSIS OF VARIANCE SUMMARY TABLE FOR DEPENDENT VARIABLE    6                  P2 amplitude
-----------------------------------------------------------------

SOURCE                 NESTING  DEGREES OF FREEDOM  SUM OF SQUARES      MEAN SQUARE      F RATIO   PROB.

                                      NUM      DEN              *SIGNIFICANT*
                                                                  *DIGITS*
                                                                  *IN SS*

A                                       2       81  0,12435556D 03 *8*  0,62177778D 02    1,4982  0,22967
B                                       2       81  0,11246222D 04 *8*  0,56231111D 03   13,5489  0,00001 loc.
AXB                                     4       81  0,85111111D 02 *6*  0,21277778D 02    0,5127  0,72656
C                       A,B            81           0,33617000D 04 *7*  0,41502469D 02
```

```
 ANALYSIS OF VARIANCE SUMMARY TABLE FOR DEPENDENT VARIABLE     7                  N2 latency
-------------------------------------------------------------------

SOURCE                NESTING  DEGREES OF FREEDOM   SUM OF SQUARES        MEAN SQUARE     F RATIO   PROB.

                                    NUM      DEN                 *SIGNIFICANT*
                                                                  *DIGITS*
                                                                  *IN SS*

A                                     2       81    0.18955556D 02 *8*   0.94777778D 01     0.9163  0.40409
B                                     2       81    0.20202222D 03 *8*   0.10101111D 03     9.7659  0.00016 loc.
AXB                                   4       81    0.20511111D 02 *7*   0.51277778D 01     0.4958  0.73886
C                     A,B            81             0.83780000D 03 *7*   0.10343210D 02
```

```
 ANALYSIS OF VARIANCE SUMMARY TABLE FOR DEPENDENT VARIABLE     8
-------------------------------------------------------------------                N2 amplitude

SOURCE                NESTING  DEGREES OF FREEDOM   SUM OF SQUARES        MEAN SQUARE     F RATIO   PROB.

                                    NUM      DEN                 *SIGNIFICANT*
                                                                  *DIGITS*
                                                                  *IN SS*

A                                     2       81    0.10369556D 04 *8*   0.51847778D 03     7.3185  0.00120 task
B                                     2       81    0.56907556D 04 *8*   0.28453778D 04    40.1637  0.00000 loc.
AXB                                   4       81    0.17717778D 03 *6*   0.44294444D 02     0.6252  0.64584
C                     A,B            81             0.57384000D 04 *7*   0.70844444D 02
```

```
ANALYSIS OF VARIANCE SUMMARY TABLE FOR DEPENDENT VARIABLE      9                        P3 latency
----------------------------------------------------------------

SOURCE               NESTING DEGREES OF FREEDOM   SUM OF SQUARES        MEAN SQUARE    F RATIO   PROB.

                             NUM      DEN                  *SIGNIFICANT*
                                                              *DIGITS*
                                                              *IN SS*


A                             2        79     0,72131995D 02 *8*   0,36065997D 02    3,6020   0,03184 task
B                             2        79     0,34025167D 02 *8*   0,17012584D 02    1,6991   0,18946
AXB                           4        79     0,87712985D 02 *7*   0,21928246D 02    2,1900   0,07763
C                    A,B     79               0,79101111D 03 *8*   0,10012799D 02



ANALYSIS OF VARIANCE SUMMARY TABLE FOR DEPENDENT VARIABLE     10 *                     P3 amplitude
----------------------------------------------------------------

SOURCE               NESTING  DEGREES OF FREEDOM   SUM OF SQUARES        MEAN SQUARE    F RATIO   PROB.

                              NUM      DEN                  *SIGNIFICANT*
                                                               *DIGITS*
                                                               *IN SS*


A                              2        79     0,34181714D 03 *8*   0,17090857D 03    2,2550   0,11158
B                              2        79     0,64147256D 01 *8*   0,32073628D 01    0,0423   0,95859
AXB                            4        79     0,22850415D 03 *7*   0,57126037D 02    0,7537   0,55851
C                    A,B      79               0,59874556D 04 *8*   0,75790577D 02
```

---

* The design is unbalanced and the analysis of variance is only approximate.

```
ANALYSIS OF VARIANCE SUMMARY TABLE FOR DEPENDENT VARIABLE    11*
-------------------------------------------------------------------               N3 latency

SOURCE               NESTING DEGREES OF FREEDOM   SUM OF SQUARES       MEAN SQUARE     F RATIO   PROB.

                                NUM      DEN              *SIGNIFICANT*
                                                            *DIGITS*
                                                            *IN SS*

A                                 2       78      0,17455741D 03 *8*   0,87278704D 02    4,7910   0,01090 task
B                                 2       78      0,17162407D 03 *8*   0,85812037D 02    4,7104   0,01171 loc.
AXB                               4       78      0,65102910D 02 *7*   0,16275728D 02    0,8934   0,47204
C                    A,B         78               0,14209556D 04 *7*   0,18217379D 02
```

```
ANALYSIS OF VARIANCE SUMMARY TABLE FOR DEPENDENT VARIABLE    12*
-------------------------------------------------------------------               N3 amplitude

SOURCE               NESTING DEGREES OF FREEDOM   SUM OF SQUARES       MEAN SQUARE     F RATIO   PROB.

                                NUM      DEN              *SIGNIFICANT*
                                                            *DIGITS*
                                                            *IN SS*

A                                 2       78      0,12582725D 03 *8*   0,62913624D 02    1,0822   0,34389
B                                 2       78      0,52542407D 03 *8*   0,26271204D 03    4,5189   0,01390 loc.
AXB                               4       78      0,39477910D 03 *7*   0,98694775D 02    1,6977   0,15899
C                    A,B         78               0,45346000D 04 *8*   0,58135897D 02
```

---

* The design is unbalanced and the analysis of variance is only approximate.

```
ANALYSIS OF VARIANCE SUMMARY TABLE FOR DEPENDENT VARIABLE    13                 P4 latency
------------------------------------------------------------------

SOURCE                NESTING  DEGREES OF FREEDOM   SUM OF SQUARES        MEAN SQUARE     F RATIO   PROB.

                                 NUM       DEN                 *SIGNIFICANT*
                                                                 *DIGITS*
                                                                 *IN SS*

A                                  2        81      0.24035556D 03 *8*   0.12017778D 03   11.8770  0.00003 task
B                                  2        81      0.48688889D 02 *8*   0.24344444D 02    2.4059  0.09660
AXB                                4        81      0.59777778D 01 *6*   0.14944444D 01    0.1477  0.96352
C                     A,B         81                0.81960000D 03 *7*   0.10118519D 02


ANALYSIS OF VARIANCE SUMMARY TABLE FOR DEPENDENT VARIABLE    14                 P4 amplitude
------------------------------------------------------------------

SOURCE                NESTING  DEGREES OF FREEDOM   SUM OF SQUARES        MEAN SQUARE     F RATIO   PROB.

                                 NUM       DEN                 *SIGNIFICANT*
                                                                 *DIGITS*
                                                                 *IN SS*

A                                  2        81      0.56880000D 03 *8*   0.28440000D 03    2.4187  0.09544
B                                  2        81      0.60354667D 04 *8*   0.30177333D 04   25.6645  0.00000 loc.
AXB                                4        81      0.21793333D 03 *6*   0.54483333D 02    0.4634  0.76241
C                     A,B         81                0.95243000D 04 *7*   0.11758395D 03
```

APPENDIX 3

```
ANALYSIS OF VARIANCE SUMMARY TABLE FOR DEPENDENT VARIABLE    15                 N4  latency
-----------------------------------------------------------------

SOURCE                  NESTING DEGREES OF FREEDOM   SUM OF SQUARES       MEAN SQUARE     F RATIO   PROB.

                                NUM      DEN                  *SIGNIFICANT*
                                                                *DIGITS*
                                                                *IN SS*

A                                 2       81     0.4681866/D 04 *8*   0.23409333D 04   18.1924  0.00000  task
B                                 2       81     0.25820000D 03 *8*   0.12910000D 03    1.0033  0.37118
AXB                               4       81     0.23353333D 03 *6*   0.58383333D 02    0.4537  0.76940
C                       A,B      81              0.10422800D 05 *7*   0.12867654D 03


ANALYSIS OF VARIANCE SUMMARY TABLE FOR DEPENDENT VARIABLE    16                 N4  amplitude
-----------------------------------------------------------------

SOURCE                  NESTING DEGREES OF FREEDOM   SUM OF SQUARES       MEAN SQUARE     F RATIO   PROB.

                                NUM      DEN                  *SIGNIFICANT*
                                                                *DIGITS*
                                                                *IN SS*

A                                 2       81     0.25735556D 03 *8*   0.12867778D 03    1.3438  0.26659
B                                 2       81     0.33944222D 04 *8*   0.16972111D 04   17.7249  0.00000  loc.
AXB                               4       81     0.12844444D 03 *6*   0.32111111D 02    0.3354  0.85340
C                       A,B      81              0.77560000D 04 *7*   0.95753086D 02
```

APPENDIX 3

```
ANALYSIS OF VARIANCE SUMMARY TABLE FOR DEPENDENT VARIABLE     17                          P5 latency
-------------------------------------------------------------------

SOURCE                 NESTING  DEGREES OF FREEDOM   SUM OF SQUARES        MEAN SQUARE    F RATIO    PROB.

                                   NUM      DEN                *SIGNIFICANT*
                                                                 *DIGITS*
                                                                 *IN SS*

A                                    2       81     0,21281556D 04 *8*   0,10640778D 04   13,8786  0,00001  task
B                                    2       81     0,11215556D 03 *8*   0,56077778D 02    0,7314  0,48438
AXB                                  4       81     0,67844444D 02 *6*   0,16961111D 02    0,2212  0,92587
C                       A,B         81              0,62103000D 04 *7*   0,76670370D 02
```

```
ANALYSIS OF VARIANCE SUMMARY TABLE FOR DEPENDENT VARIABLE     18                          P5 amplitude
-------------------------------------------------------------------

SOURCE                 NESTING  DEGREES OF FREEDOM   SUM OF SQUARES        MEAN SQUARE    F RATIO    PROB.

                                   NUM      DEN                *SIGNIFICANT*
                                                                 *DIGITS*
                                                                 *IN SS*

A                                    2       81     0,17155556D 02 *8*   0,85777778D 01    0,1538  0,85766
B                                    2       81     0,74108889D 03 *8*   0,37054444D 03    6,6456  0,00213  loc.
AXB                                  4       81     0,13931111D 03 *7*   0,34827778D 02    0,6246  0,64627
C                       A,B         81              0,45164000D 04 *8*   0,55758025D 02
```

APPENDIX 3

```
ANALYSIS OF VARIANCE SUMMARY TABLE FOR DEPENDENT VARIABLE    19                         RMS  value of E.E.G.
-----------------------------------------------------------------

SOURCE                 NESTING  DEGREES OF FREEDOM   SUM OF SQUARES       MEAN SQUARE    F RATIO   PROB.

                                   NUM      DEN                *SIGNIFICANT*
                                                                 *DIGITS*
                                                                 *IN SS*

A                                   2        81      0.70242222D 03 *8*   0.35121111D 03   0.6158  0.54272
B                                   2        81      0.67309356D 05 *8*   0.33654678D 05  59.0092  0.00000 loc.
AXB                                 4        81      0.51984444D 03 *5*   0.12996111D 03   0.2279  0.92204
C                      A,B         81                0.46196700D 05 *7*   0.57032963D 03
```

```
ANALYSIS OF VARIANCE SUMMARY TABLE FOR DEPENDENT VARIABLE    20                         S.D. of evoked potential
-----------------------------------------------------------------

SOURCE                 NESTING  DEGREES OF FREEDOM   SUM OF SQUARES       MEAN SQUARE    F RATIO   PROB.

                                   NUM      DEN                *SIGNIFICANT*
                                                                 *DIGITS*
                                                                 *IN SS*

A                                   2        81      0.18995556D 03 *8*   0.94977778D 02   0.3413  0.71183
B                                   2        81      0.15333956D 05 *8*   0.76669778D 04  27.5545  0.00000 loc.
AXB                                 4        81      0.26031111D 03 *6*   0.65077778D 02   0.2339  0.91852
C                      A,B         81                0.22538100D 05 *7*   0.27824815D 03
```

```
ANALYSIS OF VARIANCE SUMMARY TABLE FOR DEPENDENT VARIABLE     1              P1  latency
-------------------------------------------------------------------

     SOURCE             DEGREES OF FREEDOM   SUM OF SQUARES       MEAN SQUARE     F RATIO   PROB.

                         NUM      DEN                  *SIGNIFICANT*
                                                          *DIGITS*
                                                          *IN SS*

     A                      2       18       0,30526667D 03 *8*   0,15263333D 03   2,9129  0,08017
     AXC                   18                0,94317778D 03 *7*   0,52398765D 02

     B                      2       18       0,31200000D 02 *8*   0,15600000D 02   0,4515  0,64368
     BXC                   18                0,62191111D 03 *7*   0,34550617D 02
                                                                                                   task*
     AXB                    4       36       0,32413333D 03 *7*   0,81033333D 02   3,1297  0,02622 loc.
     AXBXC                 36                0,93208889D 03 *7*   0,25891358D 02

     C                      9                0,12502222D 04 *8*   0,13891358D 03

ANALYSIS OF VARIANCE SUMMARY TABLE FOR DEPENDENT VARIABLE     2              P1  amplitude
-------------------------------------------------------------------

     SOURCE             DEGREES OF FREEDOM   SUM OF SQUARES       MEAN SQUARE     F RATIO   PROB.

                         NUM      DEN                  *SIGNIFICANT*
                                                          *DIGITS*
                                                          *IN SS*

     A                      2       18       0,54155556D 02 *8*   0,27077778D 02   0,6773  0,52047
     AXC                   18                0,71962222D 03 *7*   0,39979012D 02

     B                      2       18       0,67222222D 02 *8*   0,33611111D 02   1,8303  0,18899
     BXC                   18                0,33055556D 03 *7*   0,18364198D 02

     AXB                    4       36       0,12871111D 03 *7*   0,32177778D 02   2,3160  0,07595
     AXBXC                 36                0,50017778D 03 *7*   0,13893827D 02

     C                      9                0,51534444D 03 *8*   0,57260494D 02
```

APPENDIX 3

```
ANALYSIS OF VARIANCE SUMMARY TABLE FOR DEPENDENT VARIABLE      3             N1  latency
------------------------------------------------------------------------

          SOURCE          DEGREES OF FREEDOM   SUM OF SQUARES        MEAN SQUARE    F RATIO   PROB.

                               NUM      DEN                *SIGNIFICANT*
                                                              *DIGITS*
                                                              *IN SS*

          A                      2       18     0.67326667D 03 *8*   0.33663333D 03    5.9584  0.01033 task
          AXC                   18              0.10169556D 04 *7*   0.56497531D 02

          B                      2       18     0.15166667D 03 *8*   0.75833333D 02    1.3959  0.27317
          BXC                   18              0.97788889D 03 *7*   0.54327160D 02

          AXB                    4       36     0.13986667D 03 *7*   0.34966667D 02    1.2407  0.31114
          AXBXC                 36              0.10145778D 04 *7*   0.28182716D 02

          C                      9              0.77017778D 03 *8*   0.85575309D 02

ANALYSIS OF VARIANCE SUMMARY TABLE FOR DEPENDENT VARIABLE      4             N1  amplitude
------------------------------------------------------------------------

          SOURCE          DEGREES OF FREEDOM   SUM OF SQUARES        MEAN SQUARE    F RATIO   PROB.

                               NUM      DEN                *SIGNIFICANT*
                                                              *DIGITS*
                                                              *IN SS*

          A                      2       18     0.58200000D 02 *8*   0.29100000D 02    0.8379  0.44881
          AXC                   18              0.62513333D 03 *7*   0.34729630D 02

          B                      2       18     0.61266667D 02 *8*   0.30633333D 02    4.8340  0.02088 loc.
          BXC                   18              0.11406667D 03 *7*   0.63370370D 01

          AXB                    4       36     0.47333333D 02 *7*   0.11833333D 02    0.7253  0.58046
          AXBXC                 36              0.58733333D 03 *7*   0.16314815D 02

          C                      9              0.53156667D 03 *8*   0.59062963D 02
```

```
ANALYSIS OF VARIANCE SUMMARY TABLE FOR DEPENDENT VARIABLE      5              P2  latency
--------------------------------------------------------------

       SOURCE            DEGREES OF FREEDOM   SUM OF SQUARES        MEAN SQUARE    F RATIO    PROB.

                              NUM      DEN                 *SIGNIFICANT*
                                                             *DIGITS*
                                                             *IN SS*


       A                        2       18    0.33646667D 03 *8*  0.16823333D 03    7.5709  0.00411  task
       AXC                     18             0.39997778D 03 *7*  0.22220988D 02

       B                        2       18    0.10980000D 03 *8*  0.54900000D 02    1.1654  0.33425
       BXC                     18             0.84797778D 03 *7*  0.47109877D 02

       AXB                      4       36    0.36333333D 02 *6*  0.90833333D 01    0.4119  0.79888
       AXBXC                   36             0.79388889D 03 *7*  0.22052469D 02

       C                        9             0.33755556D 03 *8*  0.37506173D 02

ANALYSIS OF VARIANCE SUMMARY TABLE FOR DEPENDENT VARIABLE      6             P2  amplitude
--------------------------------------------------------------

       SOURCE            DEGREES OF FREEDOM   SUM OF SQUARES        MEAN SQUARE    F RATIO    PROB.

                              NUM      DEN                 *SIGNIFICANT*
                                                             *DIGITS*
                                                             *IN SS*


       A                        2       18    0.12435556D 03 *8*  0.62177778D 02    0.7907  0.46865
       AXC                     18             0.14154222D 04 *7*  0.78634568D 02

       B                        2       18    0.11246222D 04 *8*  0.56231111D 03   23.3312  0.00001 loc.
       BXC                     18             0.43382222D 03 *7*  0.24101235D 02

       AXB                      4       36    0.85111111D 02 *6*  0.21277778D 02    0.9634  0.43940
       AXBXC                   36             0.79511111D 03 *7*  0.22086420D 02

       C                        9             0.71734444D 03 *8*  0.79704938D 02
```

APPENDIX 3

```
ANALYSIS OF VARIANCE SUMMARY TABLE FOR DEPENDENT VARIABLE     7              N2  latency
-------------------------------------------------------------

                SOURCE          DEGREES OF FREEDOM   SUM OF SQUARES       MEAN SQUARE    F RATIO   PROB.

                                    NUM      DEN                *SIGNIFICANT*
                                                                  *DIGITS*
                                                                  *IN SS*

                A                     2       18     0.18955556D 02 *8*   0.94777778D 01    0.5871  0.56626
                AXC                  18              0.29060000D 03 *7*   0.16144444D 02

                B                     2       18     0.20202222D 03 *8*   0.10101111D 03   19.4391  0.00003 loc.
                BXC                  18              0.93533333D 02 *7*   0.51962963D 01

                AXB                   4       36     0.20511111D 02 *7*   0.51277778D 01    0.5167  0.72390
                AXBXC                36              0.35726667D 03 *7*   0.99240741D 01

                C                     9              0.96400000D 02 *8*   0.10711111D 02
```

```
ANALYSIS OF VARIANCE SUMMARY TABLE FOR DEPENDENT VARIABLE     8              N2  amplitude
-------------------------------------------------------------

             SOURCE             DEGREES OF FREEDOM   SUM OF SQUARES       MEAN SQUARE    F RATIO   PROB.

                                    NUM      DEN                *SIGNIFICANT*
                                                                  *DIGITS*
                                                                  *IN SS*

             A                        2       18     0.10369556D 04 *8*   0.51847778D 03    5.6449  0.01250 task
             AXC                     18              0.16532667D 04 *7*   0.91848148D 02

             B                        2       18     0.56907556D 04 *8*   0.28453778D 04   55.1430  0.00000 loc.
             BXC                     18              0.92880000D 03 *7*   0.51600000D 02

             AXB                      4       36     0.17717778D 03 *6*   0.44294444D 02    1.1326  0.35666
             AXBXC                   36              0.14079333D 04 *7*   0.39109259D 02

             C                        9              0.17484000D 04 *8*   0.19426667D 03
```

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APPENDIX 3

```
ANALYSIS OF VARIANCE SUMMARY TABLE FOR DEPENDENT VARIABLE    13              P4 latency
------------------------------------------------------------------

               SOURCE        DEGREES OF FREEDOM   SUM OF SQUARES        MEAN SQUARE     F RATIO    PROB.

                                 NUM      DEN                *SIGNIFICANT*
                                                                *DIGITS*
                                                                *IN SS*


               A                   2       18     0,24035556D 03 *8*   0,12017778D 03     9,3295  0,00166  task
               AXC                18              0,23186667D 03 *7*   0,12881481D 02

               B                   2       18     0,48688889D 02 *8*   0,24344444D 02     4,3158  0,02944  loc.
               BXC                18              0,10153333D 03 *7*   0,56407407D 01

               AXB                 4       36     0,59777778D 01 *6*   0,14944444D 01     0,2418  0,91271
               AXBXC              36              0,22246667D 03 *7*   0,61796296D 01

               C                   9              0,26373333D 03 *8*   0,29303704D 02
ANALYSIS OF VARIANCE SUMMARY TABLE FOR DEPENDENT VARIABLE    14              P4 amplitude
------------------------------------------------------------------

               SOURCE        DEGREES OF FREEDOM   SUM OF SQUARES        MEAN SQUARE     F RATIO    PROB.

                                 NUM      DEN                *SIGNIFICANT*
                                                                *DIGITS*
                                                                *IN SS*


               A                   2       18     0,56880000D 03 *8*   0,28440000D 03     8,1504  0,00302  task
               AXC                18              0,62808889D 03 *6*   0,34893827D 02

               B                   2       18     0,60354667D 04 *8*   0,30177333D 04    52,2590  0,00000  loc.
               BXC                18              0,10394222D 04 *6*   0,57745679D 02

               AXB                 4       36     0,21793333D 03 *6*   0,54483333D 02     2,4239  0,06587
               AXBXC              36              0,80917778D 03 *6*   0,22477160D 02

               C                   9              0,70476111D 04 *8*   0,78306790D 03
```

```
ANALYSIS OF VARIANCE SUMMARY TABLE FOR DEPENDENT VARIABLE    15
--------------------------------------------------------------                    N4  latency

          SOURCE          DEGREES OF FREEDOM   SUM OF SQUARES        MEAN SQUARE    F RATIO    PROB.

                             NUM      DEN                *SIGNIFICANT*
                                                            *DIGITS*
                                                            *IN SS*

          A                    2       18      0.46818667D 04 *8*    0.23409333D 04   11.2241   0.00068  task
          AXC                 18               0.37541333D 04 *7*    0.20856296D 03

          B                    2       18      0.25820000D 03 *8*    0.12910000D 03    1.7733   0.19818
          BXC                 18               0.13104667D 04 *7*    0.72803704D 02

          AXB                  4       36      0.23353333D 03 *6*    0.58383333D 02    1.2724   0.29881
          AXBXC               36               0.16518000D 04 *7*    0.45883333D 02

          C                    9               0.37064000D 04 *8*    0.41182222D 03
```

```
ANALYSIS OF VARIANCE SUMMARY TABLE FOR DEPENDENT VARIABLE    16
--------------------------------------------------------------                    N4  amplitude

          SOURCE          DEGREES OF FREEDOM   SUM OF SQUARES        MEAN SQUARE    F RATIO    PROB.

                             NUM'     DEN                *SIGNIFICANT*
                                                            *DIGITS*
                                                            *IN SS*

          A                    2       18      0.25735556D 03 *8*    0.12867778D 03    3.1452   0.06738
          AXC                 18               0.73642222D 03 *7*    0.40912346D 02

          B                    2       18      0.33944222D 04 *8*    0.16972111D 04   19.3187   0.00003  loc.
          BXC                 18               0.15813556D 04 *7*    0.87853086D 02

          AXB                  4       36      0.12844444D 03 *6*    0.32111111D 02    1.4600   0.23464
          AXBXC               36               0.79177778D 03 *6*    0.21993827D 02

          C                    9               0.46464444D 04 *8*    0.51627160D 03
```

```
ANALYSIS OF VARIANCE SUMMARY TABLE FOR DEPENDENT VARIABLE    17           P5  latency
-------------------------------------------------------------------

          SOURCE           DEGREES OF FREEDOM   SUM OF SQUARES        MEAN SQUARE    F RATIO   PROB.

                                NUM      DEN                 *SIGNIFICANT*
                                                               *DIGITS*
                                                                *IN SS*


          A                       2       18    0.21281556D 04 *8*   0.10640778D 04   20.0103  0.00003 task
          AXC                    18             0.95717778D 03 *7*   0.53176543D 02

          B                       2       18    0.11215556D 03 *8*   0.56077778D 02    0.7991  0.46506
          BXC                    18             0.12631778D 04 *7*   0.70176543D 02

          AXB                     4       36    0.67844444D 02 *6*   0.16961111D 02    0.2454  0.91056
          AXBXC                  36             0.24881556D 04 *7*   0.69115432D 02

          C                       9             0.15017889D 04 *8*   0.16686543D 03
```

```
ANALYSIS OF VARIANCE SUMMARY TABLE FOR DEPENDENT VARIABLE    18           P5  amplitude
-------------------------------------------------------------------

          SOURCE           DEGREES OF FREEDOM   SUM OF SQUARES        MEAN SQUARE    F RATIO   PROB.

                                NUM      DEN                 *SIGNIFICANT*
                                                               *DIGITS*
                                                                *IN SS*


          A                       2       18    0.17155556D 02 *8*   0.85777778D 01    0.1866  0.83137
          AXC                    18             0.82751111D 03 *7*   0.45972840D 02

          B                       2       18    0.74108889D 03 *8*   0.37054444D 03    6.4908  0.00754 loc.
          BXC                    18             0.10275778D 04 *7*   0.57087654D 02

          AXB                     4       36    0.13931111D 03 *7*   0.34827778D 02    1.6439  0.18452
          AXBXC                  36             0.76268889D 03 *7*   0.21185802D 02

          C                       9             0.18986222D 04 *8*   0.21095802D 03
```

```
ANALYSIS OF VARIANCE SUMMARY TABLE FOR DEPENDENT VARIABLE    19              RMS value of  EEG.
-----------------------------------------------------------------

           SOURCE          DEGREES OF FREEDOM   SUM OF SQUARES       MEAN SQUARE    F RATIO   PROB.

                                NUM      DEN                 *SIGNIFICANT*
                                                               *DIGITS*
                                                               *IN SS*

           A                      2       18     0.70242222D 03 *8*   0.35121111D 03    1.1395  0.34200
           AXC                   18              0.55478000D 04 *7*   0.30821111D 03

           B                      2       18     0.67309356D 05 *8*   0.33654678D 05   24.4634  0.00001  loc.
           BXC                   18              0.24762867D 05 *7*   0.13757148D 04

           AXB                    4       36     0.51984444D 03 *5*   0.12996111D 03    0.9145  0.46603
           AXBXC                 36              0.51159333D 04 *6*   0.14210926D 03

           C                      9              0.10770100D 05 *8*   0.11966778D 04
ANALYSIS OF VARIANCE SUMMARY TABLE FOR DEPENDENT VARIABLE    20             SD of evoked potential
-----------------------------------------------------------------

           SOURCE          DEGREES OF FREEDOM   SUM OF SQUARES       MEAN SQUARE    F RATIO   PROB.

                                NUM      DEN                 *SIGNIFICANT*
                                                               *DIGITS*
                                                               *IN SS*

           A                      2       18     0.18995556D 03 *8*   0.94977778D 02    1.1193  0.34820
           AXC                   18              0.15273778D 04 *7*   0.84854321D 02

           B                      2       18     0.15333956D 05 *8*   0.76669778D 04   40.0708  0.00000 loc.
           BXC                   18              0.34440444D 04 *7*   0.19133580D 03

           AXB                    4       36     0.26031111D 03 *6*   0.65077778D 02    1.9649  0.12084
           AXBXC                 36              0.11923556D 04 *6*   0.33120988D 02

           C                      9              0.16374322D 05 *8*   0.18193691D 04
```

```
ANALYSIS OF VARIANCE SUMMARY TABLE FOR DEPENDENT VARIABLE      1            P1  latency
-----------------------------------------------------------------

SOURCE                 NESTING DEGREES OF FREEDOM   SUM OF SQUARES       MEAN SQUARE    F RATIO   PROB,

                                NUM      DEN                  *SIGNIFICANT*
                                                                 *DIGITS*
                                                                 *IN SS*

A                                 2        2     0,30526667D 03 *8*   0,15263333D 03   31,1497  0,03110 task

B                                 2        2     0,31200000D 02 *8*   0,15600000D 02    0,7500  0,57143

AXB                               4        4     0,32413333D 03 *7*   0,81033333D 02    4,3802  0,09080

C                                 1       72     0,90000000D 02 *8*   0,90000000D 02    1,8347  0,17981
AXC                               2       72     0,98000000D 01 *6*   0,49000000D 01    0,0999  0,90507
BXC                               2       72     0,41600000D 02 *7*   0,20800000D 02    0,4240  0,65604
AXBXC                             4       72     0,74000000D 02 *7*   0,18500000D 02    0,3771  0,82425
D                      A,B,C     72              0,35320000D 04 *8*   0,49055556D 02
ANALYSIS OF VARIANCE SUMMARY TABLE FOR DEPENDENT VARIABLE      2            P1  amplitude
-----------------------------------------------------------------

SOURCE                 NESTING DEGREES OF FREEDOM   SUM OF SQUARES       MEAN SQUARE    F RATIO   PROB,

                                NUM.     DEN                  *SIGNIFICANT*
                                                                 *DIGITS*
                                                                 *IN SS*

A                                 2        2     0,54155556D 02 *8*   0,27077778D 02    0,1383  0,87848

B                                 2        2     0,67222222D 02 *8*   0,33611111D 02    8,9763  0,10024

AXB                               4        4     0,12871111D 03 *7*   0,32177778D 02    5,3530  0,06653

C                                 1       72     0,27777778D 00 *8*   0,27777778D 00    0,0122  0,91244
AXC                               2       72     0,39148889D 03 *8*   0,19574444D 03    8,5811  0,00045 task* speed
BXC                               2       72     0,74888889D 01 *7*   0,37444444D 01    0,1642  0,84893
AXBXC                             4       72     0,24044444D 02 *6*   0,60111111D 01    0,2635  0,90043
D                      A,B,C     72              0,16424000D 04 *7*   0,22811111D 02
```

APPENDIX 3

```
ANALYSIS OF VARIANCE SUMMARY TABLE FOR DEPENDENT VARIABLE      3           N1  latency
-----------------------------------------------------------------

SOURCE                NESTING DEGREES OF FREEDOM   SUM OF SQUARES        MEAN SQUARE    F RATIO   PROB.

                              NUM      DEN                  *SIGNIFICANT*
                                                              *DIGITS*
                                                              *IN SS*


A                              2        2      0.67326667D 03 *8*   0.33663333D 03  618.3061  0.00161 task

B                              2        2      0.15166667D 03 *8*   0.75833333D 02    0.4867  0.67263

AXB                            4        4      0.13986667D 03 *7*   0.34966667D 02    4.1408  0.09880

C                              1       72      0.10671111D 03 *8*   0.10671111D 03    2.3098  0.13294
AXC                            2       72      0.10888889D 01 *5*   0.54444444D 00    0.0118  0.98829 loc.*
BXC                            2       72      0.31162222D 03 *7*   0.15581111D 03    3.3725  0.03980 speed
AXBXC                          4       72      0.33777778D 02 *6*   0.84444444D 01    0.1828  0.94663
D                     A,B,C   72               0.33264000D 04 *7*   0.46200000D 02
```

```
ANALYSIS OF VARIANCE SUMMARY TABLE FOR DEPENDENT VARIABLE      4           N1  amplitude
-----------------------------------------------------------------

SOURCE                NESTING DEGREES OF FREEDOM   SUM OF SQUARES        MEAN SQUARE    F RATIO   PROB.

                              NUM      DEN                  *SIGNIFICANT*
                                                              *DIGITS*
                                                              *IN SS*


A                              2        2      0.58200000D 02 *8*   0.29100000D 02    0.6408  0.60945

B                              2        2      0.61266667D 02 *8*   0.30633333D 02    8.8083  0.10195

AXB                            4        4      0.47333333D 02 *7*   0.11833333D 02    0.5344  0.72061

C                              1       72      0.93444444D 01 *8*   0.93444444D 01    0.4047  0.52668
AXC                            2       72      0.90822222D 02 *7*   0.45411111D 02    1.9668  0.14735
BXC                            2       72      0.69555556D 01 *7*   0.34777778D 01    0.1506  0.86044
AXBXC                          4       72      0.88577778D 02 *7*   0.22144444D 02    0.9591  0.43531
D                     A,B,C   72               0.16624000D 04 *8*   0.23088889D 02
```

```
ANALYSIS OF VARIANCE SUMMARY TABLE FOR DEPENDENT VARIABLE     5            P2 latency
--------------------------------------------------------------------

SOURCE               NESTING DEGREES OF FREEDOM   SUM OF SQUARES        MEAN SQUARE     F RATIO    PROB.

                              NUM      DEN                   *SIGNIFICANT*
                                                                *DIGITS*
                                                                *IN SS*


A                              2         2     0,33646667D 03 *8*   0,16823333D 03   10,6253   0,08602

B                              2         2     0,10980000D 03 *8*   0,54900000D 02    2,4256   0,29192

AXB                            4         4     0,36333333D 02 *6*   0,90833333D 01    0,5567   0,70781

C                              1        72     0,0            *9*   0,0               0,0      1,00000
AXC                            2        72     0,31666667D 02 *7*   0,15833333D 02    0,5096   0,60291
BXC                            2        72     0,45266667D 02 *7*   0,22633333D 02    0,7284   0,48620
AXBXC                          4        72     0,65266667D 02 *7*   0,16316667D 02    0,5251   0,71757
D                    A,B,C    72               0,22372000D 04 *7*   0,31072222D 02

ANALYSIS OF VARIANCE SUMMARY TABLE FOR DEPENDENT VARIABLE     6            P2 amplitude
--------------------------------------------------------------------

SOURCE               NESTING DEGREES OF FREEDOM   SUM OF SQUARES        MEAN SQUARE     F RATIO    PROB.

                              NUM      DEN                   *SIGNIFICANT*
                                                                *DIGITS*
                                                                *IN SS*


A                              2         2     0,12435556D 03 *8*   0,62177778D 02    0,7163   0,58264

B                              2         2     0,11246222D 04 *8*   0,56231111D 03   21,1926   0.04506 loc.

AXB                            4         4     0,85111111D 02 *6*   0,21277778D 02    2,7875   0,17232

C                              1        72     0,39690000D 03 *8*   0,39690000D 03   10,5543   0,00176 speed
AXC                            2        72     0,17360000D 03 *7*   0,86800000D 02    2,3082   0,10676
BXC                            2        72     0,53066667D 02 *6*   0,26533333D 02    0,7056   0,49721
AXBXC                          4        72     0,30533333D 02 *6*   0,76333333D 01    0,2030   0,93595
D                    A,B,C    72               0,27076000D 04 *7*   0,37605556D 02
```

APPENDIX 3

```
ANALYSIS OF VARIANCE SUMMARY TABLE FOR DEPENDENT VARIABLE     7            N2  latency
-----------------------------------------------------------------

SOURCE                NESTING DEGREES OF FREEDOM   SUM OF SQUARES       MEAN SQUARE    F RATIO   PROB.

                                NUM     DEN                 *SIGNIFICANT*
                                                              *DIGITS*
                                                              *IN SS*

A                                2        2    0.18955556D 02 *8*   0.94777778D 01    0.3980  0.71529

B                                2        2    0.20202222D 03 *8*   0.10101111D 03  478.4737  0.00209  loc.

AXB                              4        4    0.20511111D 02 *7*   0.51277778D 01    0.2256  0.91081

C                                1       72    0.28444444D 01 *8*   0.28444444D 01    0.2943  0.58918
AXC                              2       72    0.47622222D 02 *7*   0.23811111D 02    2.4632  0.09231
BXC                              2       72    0.42222222D 00 *5*   0.21111111D 00    0.0218  0.97840
AXBXC                            4       72    0.90911111D 02 *7*   0.22727778D 02    2.3511  0.06211
D                    A,B,C      72             0.69600000D 03 *7*   0.96666667D 01

ANALYSIS OF VARIANCE SUMMARY TABLE FOR DEPENDENT VARIABLE     8            N2  amplitude
-----------------------------------------------------------------

SOURCE                NESTING DEGREES OF FREEDOM   SUM OF SQUARES       MEAN SQUARE    F RATIO   PROB.

                                NUM     DEN                 *SIGNIFICANT*
                                                              *DIGITS*
                                                              *IN SS*

A                                2        2    0.10369556D 04 *8*   0.51847778D 03    7.8756  0.11267

B                                2        2    0.56907556D 04 *8*   0.28453778D 04   43.0249  0.02271 loc.

AXB                              4        4    0.17717778D 03 *6*   0.44294444D 02    1.9848  0.26152

C                                1       72    0.60840000D 03 *8*   0.60840000D 03    9.1703  0.00341 speed
AXC                              2       72    0.13166667D 03 *6*   0.65833333D 02    0.9923  0.37574
BXC                              2       72    0.13226667D 03 *6*   0.66133333D 02    0.9968  0.37409
AXBXC                            4       72    0.89266667D 02 *6*   0.22316667D 02    0.3364  0.85259
D                    A,B,C      72             0.47768000D 04 *7*   0.66344444D 02
```

```
ANALYSIS OF VARIANCE SUMMARY TABLE FOR DEPENDENT VARIABLE      9              P3  latency
----------------------------------------------------------------
(The design is unbalanced and the results of the analysis of variance are approximate)
SOURCE                NESTING DEGREES OF FREEDOM   SUM OF SQUARES        MEAN SQUARE    F RATIO   PROB.

                               NUM      DEN               *SIGNIFICANT*
                                                             *DIGITS*
                                                             *IN SS*


A                                2        2     0.70568919D 02 *8*   0.35284459D 02    2.7972  0.26335

B                                2        2     0.33960811D 02 *8*   0.16980405D 02   11.3050  0.08127

AXB                              4        4     0.89651351D 02 *7*   0.22412838D 02    4.4711  0.08801

C                                1       70     0.49256757D 00 *8*   0.49256757D 00    0.0464  0.83002
AXC                              2       70     0.25228378D 02 *7*   0.12614189D 02    1.1891  0.31056
BXC                              2       70     0.30040541D 01 *7*   0.15020270D 01    0.1416  0.86822
AXBXC                            4       70     0.20051351D 02 *7*   0.50128378D 01    0.4726  0.75569
D                    A,B,C      70              0.74255000D 03 *7*   0.10607857D 02

ANALYSIS OF VARIANCE SUMMARY TABLE FOR DEPENDENT VARIABLE    10              P3  amplitude
----------------------------------------------------------------
( The design is unbalanced and the results of the analysis of variance are approximate)
SOURCE                NESTING DEGREES OF FREEDOM   SUM OF SQUARES        MEAN SQUARE    F RATIO   PROB.

                               NUM      DEN               *SIGNIFICANT*
                                                             *DIGITS*
                                                             *IN SS*


A                                2        2     0.34114054D 03 *8*   0.17057027D 03    0.6457  0.60766

B                                2        2     0.93891892D 01 *8*   0.46945946D 01    0.0978  0.91091

AXB                              4        4     0.24745946D 03 *7*   0.61864865D 02    1.8815  0.27772

C                                1       70     0.13926757D 03 *8*   0.13926757D 03    1.9035  0.17208 task*
AXC                              2       70     0.52836216D 03 *7*   0.26418108D 03    3.6109  0.03218 speed
BXC                              2       70     0.96005405D 02 *7*   0.48002703D 02    0.6561  0.52203
AXBXC                            4       70     0.13152432D 03 *7*   0.32881081D 02    0.4494  0.77246
D                    A,B,C      70              0.51214000D 04 *7*   0.73162857D 02
```

```
ANALYSIS OF VARIANCE SUMMARY TABLE FOR DEPENDENT VARIABLE    11            N3  latency
----------------------------------------------------------------
(The design is unbalanced and the results of the analysis of variance are approximate)
SOURCE                NESTING DEGREES OF FREEDOM   SUM OF SQUARES        MEAN SQUARE    F RATIO   PROB.

                              NUM      DEN                *SIGNIFICANT*
                                                            *DIGITS*
                                                            *IN SS*


A                               2        2     0,16992133D 03 *8*   0,84960667D 02    6,8624  0,12719

B                               2        2     0,16896133D 03 *8*   0,84480667D 02    7,6657  0,11540

AXB                             4        4     0,66646667D 02 *7*   0,16661667D 02   28,1606  0,00345 task*
                                                                                                     loc.
C                               1       69     0,66666667D 01 *8*   0,66666667D 01    0,3366  0,56370
AXC                             2       69     0,24761333D 02 *7*   0,12380667D 02    0,6251  0,53823
BXC                             2       69     0,22041333D 02 *7*   0,11020667D 02    0,5564  0,57582
AXBXC                           4       69     0,23666667D 01 *5*   0,59166667D 00    0,0299  0,99824
D                    A,B,C     69              0,13667000D 04 *7*   0,19807246D 02

ANALYSIS OF VARIANCE SUMMARY TABLE FOR DEPENDENT VARIABLE    12            N3  amplitude
----------------------------------------------------------------
        (The design is unbalanced and the results of the analysis of variance are approximate)
SOURCE                NESTING DEGREES OF FREEDOM   SUM OF SQUARES        MEAN SQUARE    F RATIO   PROB.

                              NUM      DEN                *SIGNIFICANT*
                                                            *DIGITS*
                                                            *IN SS*


A                               2        2     0,13120133D 03 *8*   0,65600667D 02    0,2977  0,77057

B                               2        2     0,58956133D 03 *8*   0,29478067D 03    6,2695  0,13756

AXB                             4        4     0,37821067D 03 *7*   0,94552667D 02    2,9653  0,15872

C                               1       69     0,10613400D 03 *8*   0,10613400D 03    1,9371  0,16846
AXC                             2       69     0,44065200D 03 *7*   0,22032600D 03    4,0212  0,02229 task*
                                                                                                     speed
BXC                             2       69     0,94036000D 02 *7*   0,47018000D 02    0,8581  0,42842
AXBXC                           4       69     0,12754400D 03 *6*   0,31886000D 02    0,5820  0,67671
D                    A,B,C     69              0,37805500D 04 *7*   0,54790580D 02
```

```
ANALYSIS OF VARIANCE SUMMARY TABLE FOR DEPENDENT VARIABLE    13          P4 latency
-----------------------------------------------------------------

SOURCE                NESTING DEGREES OF FREEDOM   SUM OF SQUARES        MEAN SQUARE     F RATIO    PROB.

                                 NUM      DEN                 *SIGNIFICANT*
                                                                *DIGITS*
                                                                *IN SS*

A                                  2        2      0.24035556D 03 *8*   0.12017778D 03   26.2524   0.03669 task

B                                  2        2      0.48688889D 02 *8*   0.24344444D 02    2.8716   0.25829

AXB                                4        4      0.59777778D 01 *6*   0.14944444D 01    0.2479   0.89727

C                                  1       72      0.51377778D 02 *8*   0.51377778D 02    5.1521   0.02621 speed
AXC                                2       72      0.91555556D 01 *6*   0.45777778D 01    0.4591   0.63372
BXC                                2       72      0.16955556D 02 *7*   0.84777778D 01    0.8501   0.43160
AXBXC                              4       72      0.24111111D 02 *6*   0.60277778D 01    0.6045   0.66067
D                     A,B,C       72               0.71800000D 03 *7*   0.99722222D 01

ANALYSIS OF VARIANCE SUMMARY TABLE FOR DEPENDENT VARIABLE    14          P4 amplitude
-----------------------------------------------------------------

SOURCE                NESTING DEGREES OF FREEDOM   SUM OF SQUARES        MEAN SQUARE     F RATIO    PROB.

                                 NUM      DEN                 *SIGNIFICANT*
                                                                *DIGITS*
                                                                *IN SS*

A                                  2        2      0.56880000D 03 *8*   0.28440000D 03    4.2071   0.19205

B                                  2        2      0.60354667D 04 *8*   0.30177333D 04  248.7143   0.00400 loc.

AXB                                4        4      0.21793333D 03 *6*   0.54483333D 02    4.6633   0.08252

C                                  1       72      0.18490000D 03 *8*   0.18490000D 03    1.4576   0.23126
AXC                                2       72      0.13520000D 03 *7*   0.67600000D 02    0.5329   0.58919
BXC                                2       72      0.24266667D 02 *5*   0.12133333D 02    0.0957   0.90890
AXBXC                              4       72      0.46733333D 02 *5*   0.11683333D 02    0.0921   0.98466
D                     A,B,C       72               0.91332000D 04 *7*   0.12685000D 03
```

```
ANALYSIS OF VARIANCE SUMMARY TABLE FOR DEPENDENT VARIABLE   15          N4 latency
------------------------------------------------------------------

SOURCE                 NESTING  DEGREES OF FREEDOM  SUM OF SQUARES       MEAN SQUARE      F RATIO   PROB.

                                   NUM      DEN                *SIGNIFICANT*
                                                                 *DIGITS*
                                                                 *IN SS*

A                                   2         2     0.46818667D 04 *8*   0.23409333D 04     3.4049  0.22702

B                                   2         2     0.25820000D 03 *8*   0.12910000D 03     0.6085  0.62168

AXB                                 4         4     0.23353333D 03 *6*   0.58383333D 02     1.4820  0.35618

C                                   1        72     0.48071111D 03 *8*   0.48071111D 03     4.3344  0.04090 speed
AXC                                 2        72     0.13750222D 04 *7*   0.68751111D 03     6.1991  0.00328 task*
BXC                                 2.       72     0.42426889D 03 *7*   0.21214444D 03     1.9128  0.15509 speed
AXBXC                               4        72     0.15757778D 03 *6*   0.39394444D 02     0.3552  0.83960
D                       A,B,C      72               0.79852000D 04 *7*   0.11090556D 03

ANALYSIS OF VARIANCE SUMMARY TABLE FOR DEPENDENT VARIABLE   16          N4 amplitude
------------------------------------------------------------------

SOURCE                 NESTING  DEGREES OF FREEDOM  SUM OF SQUARES       MEAN SQUARE      F RATIO   PROB.

                                   NUM      DEN                *SIGNIFICANT*
                                                                 *DIGITS*
                                                                 *IN SS*

A                                   2         2     0.25735556D 03 *8*   0.12867778D 03     5.8996  0.14494

B                                   2         2     0.33944222D 04 *8*   0.16972111D 04    42.4185  0.02303 loc.

AXB                                 4         4     0.12844444D 03 *6*   0.32111111D 02     1.7192  0.30626

C                                   1        72     0.44444444D 03 *8*   0.44444444D 03     4.4987  0.03737 speed
AXC                                 2        72     0.43622222D 02 *6*   0.21811111D 02     0.2208  0.80244
BXC                                 2        72     0.80022222D 02 *6*   0.40011111D 02     0.4050  0.66849
AXBXC                               4        72     0.74711111D 02 *6*   0.18677778D 02     0.1891  0.94338
D                       A,B,C      72               0.71132000D 04 *7*   0.98794444D 02
```

```
ANALYSIS OF VARIANCE SUMMARY TABLE FOR DEPENDENT VARIABLE    17             P5 latency
-------------------------------------------------------------

SOURCE                NESTING DEGREES OF FREEDOM   SUM OF SQUARES        MEAN SQUARE     F RATIO   PROB.

                              NUM      DEN                  *SIGNIFICANT*
                                                              *DIGITS*
                                                              *IN SS*


A                              2        2      0.21281556D 04 *8*   0.10640778D 04   11.5396   0.07975

B                              2        2      0.11215556D 03 *8*   0.56077778D 02    1.3564   0.42438

AXB                            4        4      0.67844444D 02 *6*   0.16961111D 02    0.2905   0.87082

C                              1       72      0.11736111D 04 *8*   0.11736111D 04   18.6287   0.00005 speed
AXC                            2       72      0.18442222D 03 *6*   0.92211111D 02    1.4637   0.23819
BXC                            2       72      0.82688889D 02 *6*   0.41344444D 02    0.6563   0.52186
AXBXC                          4       72      0.23357778D 03 *6*   0.58394444D 02    0.9269   0.45325
D                 A,B,C       72               0.45360000D 04 *7*   0.63000000D 02

ANALYSIS OF VARIANCE SUMMARY TABLE FOR DEPENDENT VARIABLE    18             P5 amplitude
-------------------------------------------------------------

SOURCE                NESTING DEGREES OF FREEDOM   SUM OF SQUARES        MEAN SQUARE     F RATIO   PROB.

                              NUM      DEN                  *SIGNIFICANT*
                                                              *DIGITS*
                                                              *IN SS*


A                              2        2      0.17155556D 02 *8*   0.85777778D 01    1.0212   0.49476

B                              2        2      0.74108889D 03 *8*   0.37054444D 03   12.7335   0.07281

AXB                            4        4      0.13931111D 03 *7*   0.34827778D 02    6.0570   0.05455

C                              1       72      0.31360000D 03 *8*   0.31360000D 03    5.5007   0.02177 speed
AXC                            2       72      0.16800000D 02 *6*   0.84000000D 01    0.1473   0.86326
BXC                            2       72      0.58200000D 02 *6*   0.29100000D 02    0.5104   0.60239
AXBXC                          4       72      0.23000000D 02 *6*   0.57500000D 01    0.1009   0.98183
D                 A,B,C       72               0.41048000D 04 *7*   0.57011111D 02
```

```
ANALYSIS OF VARIANCE SUMMARY TABLE FOR DEPENDENT VARIABLE     19             RMS value of EEG
-----------------------------------------------------------------

SOURCE                  NESTING DEGREES OF FREEDOM    SUM OF SQUARES        MEAN SQUARE     F RATIO    PROB,

                                    NUM      DEN                *SIGNIFICANT*
                                                                   *DIGITS*
                                                                   *IN SS*


A                                     2        2      0,70242222D 03 *8*   0,35121111D 03     0,3171   0,75922

B                                     2        2      0,67309356D 05 *8*   0,33654678D 05   537,3285   0,00186 loc.

AXB                                   4        4      0,51984444D 03 *5*   0,12996111D 03.    0,5695   0,70058

C                                     1       72      0,25000000D 01 *8*   0,25000000D 01     0,0042   0,94856
AXC                                   2       72      0,22148667D 04 *7*   0,11074333D 04     1,8568   0,16357
BXC                                   2       72      0,12526667D 03 *5*   0,62633333D 02     0,1050   0,90045
AXBXC                                 4       72      0,91286667D 03 *6*   0,22821667D 03     0,3827   0,82035
D                       A,B,C        72               0,42941200D 05 *7*   0,59640556D 03

ANALYSIS OF VARIANCE SUMMARY TABLE FOR DEPENDENT VARIABLE     20             SD of evoked potential
-----------------------------------------------------------------

SOURCE                  NESTING DEGREES OF FREEDOM    SUM OF SQUARES        MEAN SQUARE     F RATIO    PROB,

                                    NUM      DEN                *SIGNIFICANT*
                                                                   *DIGITS*
                                                                   *IN SS*


A                                     2        2      0,18995556D 03 *8*   0,94977778D 02     6,5754   0,13201

B                                     2        2      0,15333956D 05 *8*   0,76669778D 04   132,3922   0,00750 loc.

AXB                                   4        4      0,26031111D 03 *6*   0,65077778D 02     2,9081   0,16291

C                                     1       72      0,22002778D 04 *6*   0,22002778D 04     7,8802   0,00643 speed
AXC                                   2       72      0,28888889D 02 *6*   0,14444444D 02     0,0517   0,94962
BXC                                   2       72      0,11582222D 03 *5*   0,57911111D 02     0,2074   0,81317
AXBXC                                 4       72      0,89511111D 02 *5*   0,22377778D 02     0,0801   0,98819
D                       A,B,C        72               0,20103600D 05 *7*   0,27921667D 03
```

APPENDIX 4

ABSTRACT OF

The Nature of Cortical Activity in a Stimulus-Response Paradigm

The nature of cortical activity during a simple stimulus-response paradigm was investigated in these experiments. Evoked potential measures from three areas of the motor cortex were obtained from a single subject over many trials, under three response conditions. Statistical analysis of the measures led to rejection of three out of four preliminary null hypotheses.

Significant differences were found in the latency and amplitude of reliable peaks of the visual evoked potential due to response modality, location of recording electrodes, and speed of reaction, but none due to position of the experimental trial in time.

The results suggested that a "motor potential" enhanced the negative peak (N_2) at 164 msec latency during both finger and foot response conditions, and that recovery from this widespread discharge in turn enhanced the positive peak (P_4) at 240 msec. A pattern of cortical activation at N_2 was suggested, beginning in the left motor cortex, passing to the right, and then upwards to the vertex. The right hemisphere showed greater amplitude variance than either of the other locations. Fast reactions were associated with shorter latency in the late peaks and smaller amplitude throughout, than were slow reactions. The value of an ipsative study in evoked potential investigation was upheld.

Further research was suggested in connection with the activation pattern within the cortex, the effect of reaction speed on peak amplitudes, and the possible synchronization of the motor potential with pre-existant evoked potential elements.