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ABSTRACT

The purpose of this study was to demonstrate that the neural efficiency of the human brain as measured by parameters of sensory evoked potentials varies depending on the sensory input used within the same subject. The subjects were 213 children aged eight to 16 years, selected randomly. Computer analysis of EEG data was performed in order to discover parameters related to intelligence test scores. Results indicated: (1) the amplitude of the visual evoked potential at certain time points following the stimulus is significantly greater for high IQ subjects; and (2) it was shown that there is a tendency for high IQ subjects to have greater energy above 14 cycles in visual evoked responses when compared to low IQ subjects. There is little doubt that study of the electrical activity of the brain can be related to intellectual functioning and continued research seems justified. (Author/EK)

FINAL REPORT

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# NEURAL EFFICIENCY

# AND

# HUMAN INTELLIGENCE

John P. Ertl, Ph.D.

Center of Cybernetic Studies

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U.S. Department of

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# ACKNOWLEDGMENTS

The contributions of the following people are gratefully acknowledged:

Dr. E.W.P. Schafer, project co-ordinator. He collected and analyzed most of the data and contributed substantially to the project as a whole.

Dr. O.R. Porebski, Mathematical consultant, performed the linear discriminant analysis which yielded one of the key findings of this work.

Mr. E.R. Funke, M.Sc, provided the analog - digital conversion of data, the Fourier analysis and the engineering support.

The cooperation of the Ottawa Separate School Board and its teachers and students has been outstanding.

## SUMMARY

Neural efficiency in relation to human intelligence was the objective of this work. A significant and repeatable correlation between IQ test scores and parameters of the visual evoked potential in a sample of 573 children has been shown previously, (Ertl, 1969).

In this project we were hoping to demonstrate that the neural efficiency of the human brain as measured by certain parameters of sensory evoked potentials varies depending on the sensory input used within the same subject. We, therefore, stimulated visually, auditorally, and with a tactile stimulus, and analyzed the evoked responses from three different areas of the brain, frontal, central, and occipital. The subjects were 213 children aged 8 years to 16 years, selected randomly from our previous sample of 573.

Extensive computer analysis of the EEG data were performed in order to discover possible new parameters which are related to intelligence test scores.

By means of linear discriminant analysis, it was demonstrated that the amplitude of the visual evoked potential at certain time points following the stimulus is significantly greater for high IQ subjects. The results of the discriminant analysis are equivalent to a correlation co-efficient of -.68. This procedure, therefore, substantially improves and objectifies the method when compared to earlier techniques. These results also confirm the work of Dustman and Beck.

By means of Fourier analysis, it was shown that there is a tendency for high IQ subjects to have greater energy above 14 cycles in their visual evoked response when compared to low IQ subjects. Predictions of academic achievement from evoked potential measures, though significant (.26), is poor when compared to predictions based on IQ test scores (.6). When predicting academic achievement from evoked potential measures using only the high and low IQ subjects, (N=79), the evoked potential predicts academic achievement equally as well as IQ test scores. All the above results were obtained with visual stimulation only. Unfortunately, due to unreliability of the evoked potential in response to auditory and tactile stimulation, we were unable to show any significant correlation with any variable in the study. This unreliability appears to be due to the particular electrode placement we have used and does not mean that the auditory and tactile evoked potentials are unreliable phenomena.

There is now little doubt that careful study of the electrical activity of the human brain can be related to intellectual functioning and continued exploration seems highly justified.

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# INTRODUCTION

The search for psychological correlates of the electrical activity of the human brain started with the observations by Hans Berger that the alpha rhythm is attenuated with attention. Most of the early attempts to relate intelligence to parameters of the EEG were unsuccessful with normal subjects (reviewed by Vogel, 1969). Practically nothing was known about the source or function of the EEG in the first two decades following Berger's discovery. In the early 1950's when high speed digital computers became generally available, the analysis of complex patterns of electrical activity became feasible and the field developed rapidly.

These technical developments made possible the application of some existing neuro-physiological techniques used with animals to human subjects without surgical procedures. By means of averaging, auto and cross correlating, etc., it is possible to reduce the background noise sufficiently to study the electrical signal from the intact human brain in response to sensory stimulation. These responses are known as evoked potentials. The study of evoked potentials is now a specialized branch of Electroencephalography and it intersects many disciplines, psychology, neuro-physiology, computer science, cybernetics, etc. Just as in the early days of EEG, the study of evoked potentials has proliferated enormously. There are hundreds of studies published where basic problems are generally avoided or superficially masked by fancy statistical designs. Late comers to the field often accept highly transformed computer data at face value without understanding the basic processes or the raw data. Duplication rather than replication and validation abound in the current literature. As a result of this, it is difficult to distinguish scientific fact from spurious statistical fiction. There are few testable theories, only observations.

During the past three years with the support of the U.S.O.E, we have established a relationship between parameters of the evoked potentials and human intelligence as measured by psychometric tests. We have also proposed a theory of neural efficiency that is sufficiently explicit to permit a scientific test and it is also capable of generating new hypotheses. The findings relating to the I.Q. - evoked potential relationship have been replicated at least five times, four of these studies (Whittacker, Dustman and Beck, Bennett, and Horn) confirm our original findings and the Ford Foundation study does not.

The results of the Ford Foundation study have not yet been fully evaluated, but a preliminary (unauthorized report by one of the four principal investigators) found that using rather primative data analysis techniques, no significant correlation could be established between the latency components of the evoked potentials and some I.Q. tests or with academic achievement. As there is no published report of these findings, methodological criticism is impossible at this stage. In addition to the four direct corroborations, there is considerable indirect evidence which supports the validity of our work. The evidence is reviewed (Ertl, 1968) and consists essentially of showing that the effect of certain drugs such as thyroid hormone, riboflavin, etc., which are known to cause mental dullness, also change evoked response latencies in the expected direction. There is also vast literature on evoked potentials in relation to numerous high level psychological functions. In all of these studies, it is usually assumed or speculated that the evoked responses are the electrical signs of information processing in the brain. If this is true, and we believe it to be so, there can be little question that the neural efficiency or intelligence of the human brain can be measured through some parameters of the evoked responses.

# METHODS

A variety of samples drawn from this laboratory's basic pool of 573 primary school pupils were utilized in the present project. Thebasic sample of 573 pupils initially studied in the U.S.O.E. Project No. 6-1545 was randomly selected from the population of 7804 children attending grades 2, 3, 4, 5, 7, and 8 in the 39 schools of the Ottawa Separate School system. Samples of pupils from each of the six grades were randomly drawn independently. The working sample of 573 pupils comprised 317 male and 256 female subjects.

The test sample in the present project comprised 119 male and 94 female pupils randomly selected from our basic pool of 573 subjects. Ages ranged from 108 to 194 months and averaged 130.7 months.

In addition a criterion sample of 46 high I.Q. pupils and 33 low I.Q. pupils was selected from the basic pool. To qualify as a high I.Q. subject, a pupil had to score 120 or better on two out of the three intelligence tests used (Wechsler Intelligence Scale for Children; Primary Mental Abilities Test; Otis test of Mental Ability). To qualify as a criterion low I.Q. subject, a pupil had to score 80 or less on two out of these three tests. The EEG of these subjects derived from bi-polar electrodes (F4 - P4 in 10 - 20 system) was already on analog tape from our previous work. It was converted to digital form and analyzed in a large number of ways using our IBM 360.

Part of the data used in this project was already on file for 573 subjects as a result of testing done during U.S.O.E. project No. 6-1545. This data included scores on: The Otis Quick-Scoring Mental Ability Test (alpha or beta); The Primary Mental Abilities Test (PMA) with individual ability quotients for verbal meaning, numbers facility, spatial relations, reasoning and/or perceptual speed as well as an overall general intelligence quotient; and the individually administered Wechsler Intelligence Scale for Children (WISC) with its eleven subtests (information, comprehension, arithmetic, similarities, vocabulary, digit span, picute completion, picture arrangement, block design, object assembly, and coding as well as verbal, performance and full scale intelligence quotients.

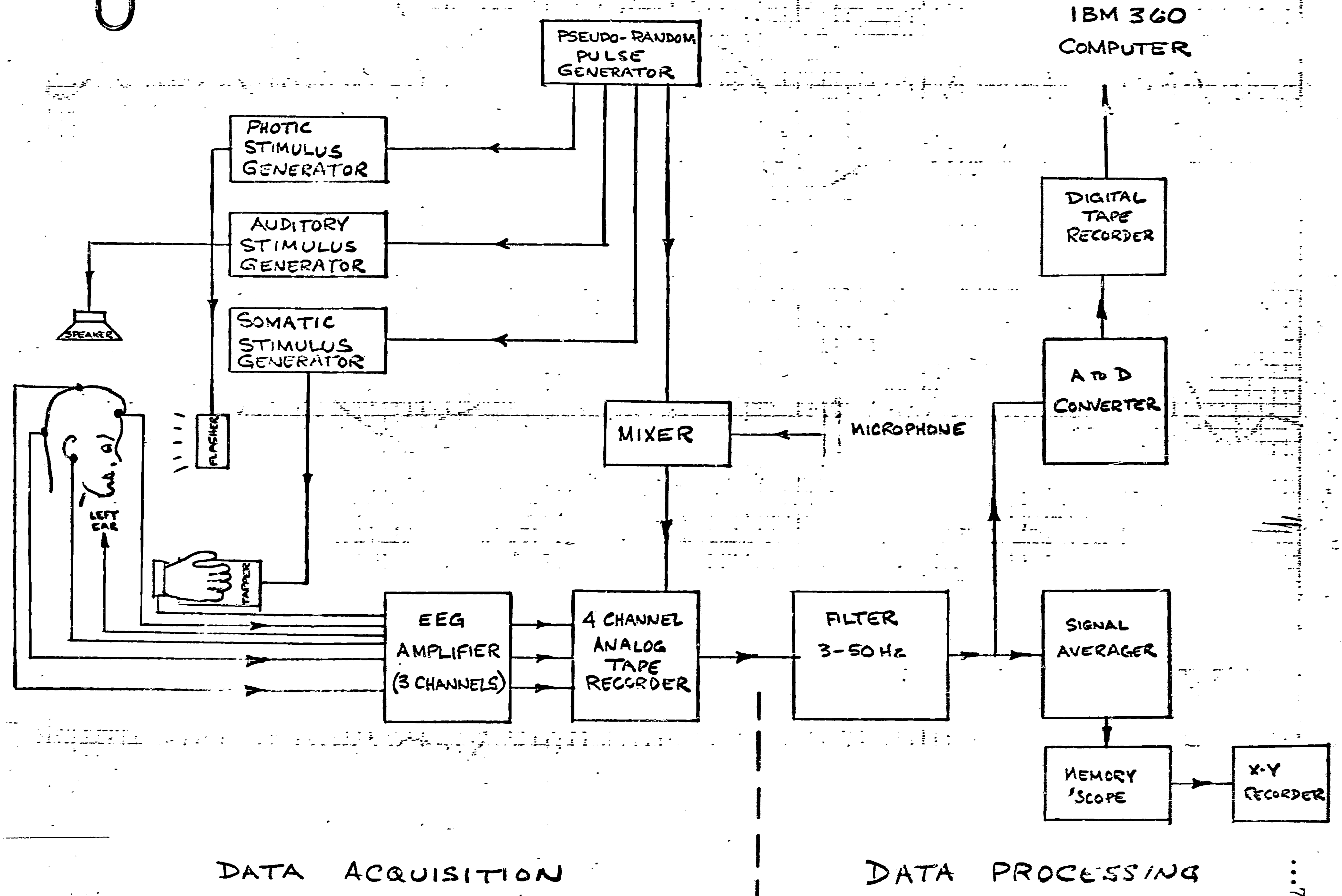
Academic achievement ratings derived from year end teacher prepared report cards were obtained for this project on 528 subjects from our data pool. For pupils in grades two and three, academic ratings (A, B, C, D) or grades in percentage scores for oral language, written language, reading, spelling, social studies, natural science and mathematics were all converted to grade percentages and averaged to obtain the academic achievement score. For pupils in grades 4 to 8, academic ratings or grade percentages for literature, language, composition, grammar, spelling, social studies, history, geography, mathematics, science, english, and french, where applicable, were all converted to grade percentages and averaged to obtain the academic success score. These academic achievement scores were subsequently correlated with the three I.Q. scores and various brain response measures to determine their relative predictive efficiency in forecasting success in school.

Scores on a specially developed Chopped Speech Test were also obtained for this project on 172 subjects. This test was devised as a putative measure of signal detection ability or the capacity to bring closure to garbled auditory information. We hypothesized that this measure would correlate with evoked potential latency. Sixty randomly selected two digit numbers at three randomized levels of item difficulty were tape recorded and presented by loudspeaker after appropriate verbal instructions. Subjects were asked to write down the two digit number they recognized after each presentation. Scores, being the total number of correct digits identified, ranged from 3 to 102 with a mean of 68.3.

Each of the 213 subjects in the major test sample were tested to determine their evoked cortical potential to visual, auditory, and tactile stimuli from three different brain areas (frontal, central, occipital). The electroencephalograph (EEG) of each subject, obtained from scalp contact electrodes at 10 - 20 derivations F3, C3, and O1 referred to A1, recorded on three channels of FM tape on a bandwidth 3 db. down, 3 - 50 Hz. Data from the C3 - A1 (central) leads was also simultaneously recorded on digital magnetic tape for subsequent processing by the University's IBM 360 - 65 system computer. A systems diagram of the instrumentation used for data acquisition and analysis is shown in Fig. 1 . Upward deflexion in the EEG indicated negativity of scalp leads with respect to the left earlobe. Four hundred bright flashes followed by 400 loudspeaker delivered click stimuli, and 400 mechanical taps to the right thumb, all presented according to a pseudo random stimulus interval distribution ranging from 0.8 to 1.8 seconds, evoked visual, auditory, and somatic brain responses. These evoked response waveforms, averaged following stimulus onset by the Enhancetron digital computer in alternate 500 millisecond duration sets of 200 responses each, enabled identification of sequential component peaks through visual cross-correlation. The relative unreliability of auditory and somatic evoked responses from frontal and occipital derivations eliminated them from further analysis. The latencies from stimulus onset of the first four reliable and reproducible peaks for visual evoked potentials from three areas and auditory and somatic evoked potentials from the central brain area were measured with an error of measurement estimated to be plus or minus 5 msec. All these sequential component latencies were inter-correlated with themselves and with the three intelligence test scores, academic achievement ratings, age and chopped speech test scores.

A variety of IBM 360 - 65 computer analyses including discriminant analysis, amplitude averaging, zero crossing, and peak histogramming, digital filtering, and fourier ratio analysis were also performed on bi-polar visual evoked potential data from the criterion

Figure 1


IBM 360 COMPUTER
PSEUDO-RANDOM PULSE GENERATOR
PHOTIC STIMULUS GENERATOR
AUDITORY STIMULUS GENERATOR
SOMATIC STIMULUS GENERATOR
SPEAKER
FLASHER
TAPPER
LEFT EAR
MIXER
MICROPHONE
DIGITAL TAPE RECORDER
A TO D CONVERTER
EEG AMPLIFIER (3 CHANNELS)
4 CHANNEL ANALOG TAPE RECORDER
FILTER 3-50 Hz
SIGNAL AVERAGER
MEMORY 'SCOPE
X-Y RECORDER
DATA ACQUISITION
DATA PROCESSING

sample and mono-polar evoked potential data from some subjects in the major test sample of 213 pupils.

A discriminant analysis on bi-polar visual evoked potential amplitude at 96 waveform data points, each four milliseconds wide, was performed to identify possible evoked potential amplitude differences between 46 high I.Q. and 33 low I.Q. subjects from our criterion sample.

Since one of the principal problems in evoked potential research is the determination of what components of the summated evoked potential waveform are in fact brain responses, a special computer analysis was developed in an attempt to attack this problem. In our previously published work (Ertl, 1968 - 1969), the processing of evoked potential data consisted of signal amplitude averaging (by small, special purpose computer) coupled with falling zero-crossing post-stimulus histogramming and associated statistical analysis. Results of these two types of analysis were used for the identification of sequential components of the evoked potential. The special computer analysis devloped for this project incorporated both amplitude averaging and falling zero-crossing histogramming as before but also included post-stimulus histogramming of leading zero-crossings, peaks and troughs of the EEG with a built-in statistical analyses for determination of significant post-stimulus brain response events.

In an attempt to further facilitate the identification of sequential visual evoked potential components with the above computer program, digital bandpass filtering of criterion high and low I.Q. subjects data was also undertaken. Digital filtering, unlike analog filtering, provides for marked attenuation of frequencies outside the bandpass with a very steep attenuation slope, and no phase shifting of the signal. Digital filtering was accomplished using rejection of components in the fourier transform and subsequently inverse fourier transforming. We used the following digital bandpass filter settings: 13 - 50 Hz, 1 - 8 Hz, and 8 - 12 Hz, for the evoked potential data of the criterion sample.

In an attempt to discover other variables of the evoked potential besides latency which might discriminate between high and low I.Q. subjects, we undertook a computer generated fourier frequency ratio analysis on our 79 criterion subjects. From a preliminary inspection of the visual evoked potentials of high and low I.Q. subjects it was hypothesized that the frequency spectrum of the high I.Q. evoked potential would contain a greater proportion of high-frequency components than that of low I.Q. visual evoked potentials. To test this hypothesis the bi-polar visual evoked potentials of our 79 criterion subjects were fast-fourier analyzed by computer (Table I Appendix A). This provided for each subject a discrete spectrum with amplitudes of frequency components at approximately 2 Hz intervals beginning with the fundamental frequency of 1.95 Hz. Since the raw EEG was originally filtered

3 - 50 Hz when transcribed from analog to digital format, the fast fourier analysis was not carried beyond 50.8 Hz. The fourier ratio was defined as the ratio of spectral energy at and above a specified breakpoint frequency to the spectral energy below that frequency. The value of the fourier ratio was then computed for breakpoint frequencies ranging from 11.7 Hz to 44.9 Hz for each of the 79 criterion subjects. For each breakpoint frequency a t test was performed to determine whether or not the fourier ratio was significantly higher for the high I.Q. subjects than for the low I.Q. subjects.

## RESULTS

The results will be considered in two parts; I. Analysis of electro physiological and psychological data based on the 1969 sample. II. Analysis done with the 1966 - 68 sample.

I(a). As a result of extensive consultations with leading researchers in this field, it was decided to change our recording technique from bi-polar to mono-polar. This turned out to be a disastrous mistake. The consequences of this decision were not forseeable at the time. Without going into the complex controversies regarding the relative advantages of the mono-polar technique over the bi-polar, the fact is that the mono-polar recording yielded unreliable evoked responses in the first 50 - 100 msec. of the response, (see Fig. 2 ). Consequently it was impossible to measure the latencies of the early components with any degree of confidence. Attempts to correlate these unreliable measures with the vast amount of data we have on our subjects is, therefore, meaningless. We have made a large number of attempts to salvage the data by various electronic techniques. They all failed and since they are of no particular scientific interest, their description is omitted. Furthermore, it will be noted from Fig. 3 that the mono-polar recording is for practical purposes unrelated to the bi-polar recording from the same site, and, therefore, the 1969 data is not comparable with the 1968 data.

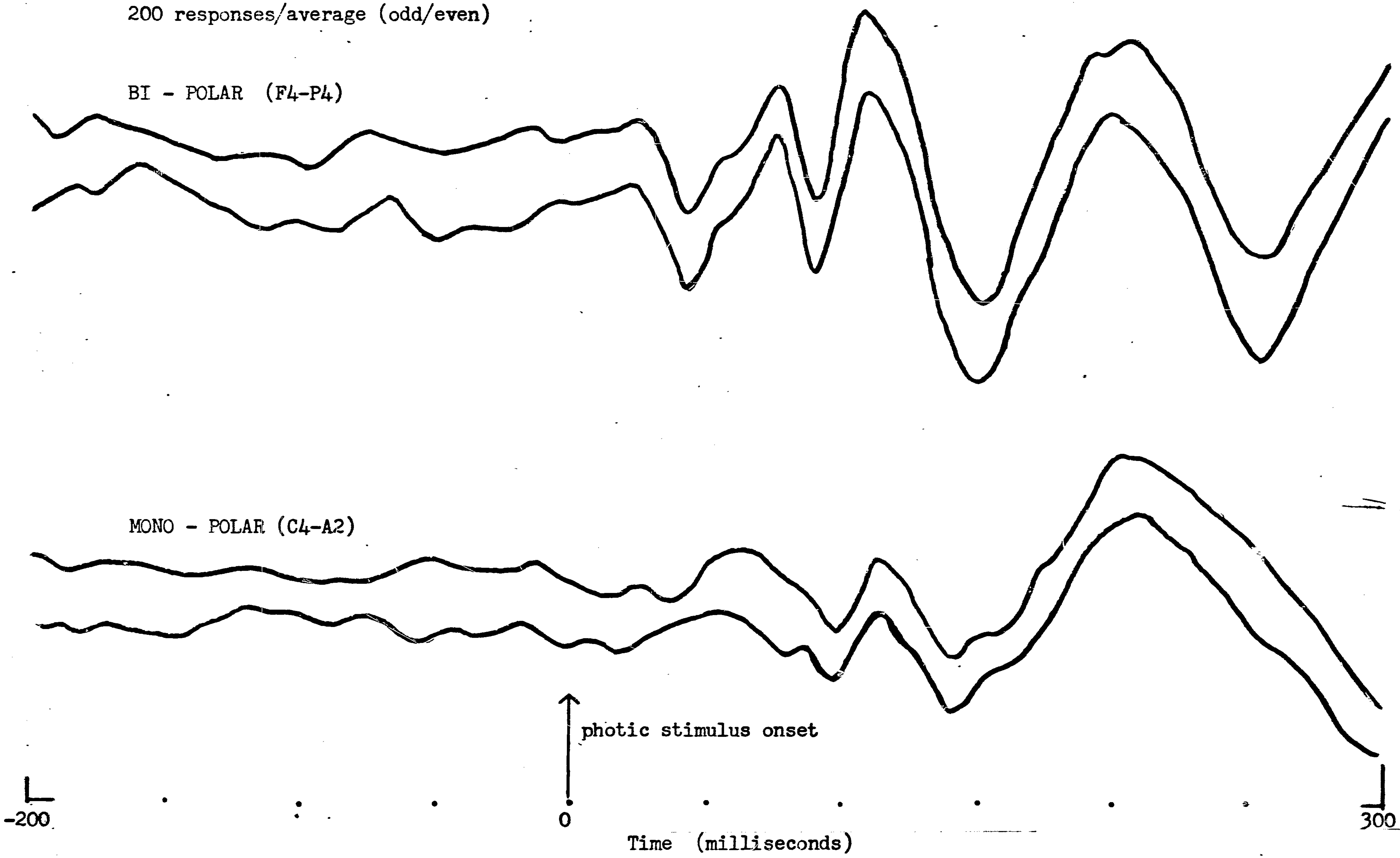
In an attempt to salvage as much as possible of our data, we went through the mono-polar records and selected only those which showed an acceptable degree of reliability, that is, odd - even reliability. Our sample size was, of course, considerably reduced and ranged from 36 subjects to 113 subjects depending on the stimulus modality and the electrode location. With the reduced sample, the following conclusion can be drawn:

1) The evoked responses to visual, auditory, and somatic stimulus from the same brain area is quite different (Fig. 4 ). This is in agreement with the results of other workers in the field and is also demonstrated by the low intercorrelations between component latencies (see Table II appendix A ). The neural processes which generate these responses must, therefore, be specific depending on stimulus modality and thus our basic assumption at the outset of this project, that neural efficiency would be different in response to different stimulus inputs, is valid.

2) The evoked responses to the same stimulus from different areas is also quite different (Fig. 5 ). This is again indicated by the low intercorrelations between components of the evoked response to the same stimulus in different areas (Table II appendix A ). This finding is unexpected because with bi-polar electrodes, the differences when going from occipital to central to frontal regions are much less. It is, therefore, clear that from the point of view

Contrast Between Reliability of Bipolar & Monopolar Visual Evoked Potentials

Figure 2



Subject: T.S.
EEG 3-50 Hz
200 responses/average (odd/even)

## Visual Evoked Responses From Bipolar & Monopolar Electrode Derivations

Figure 3

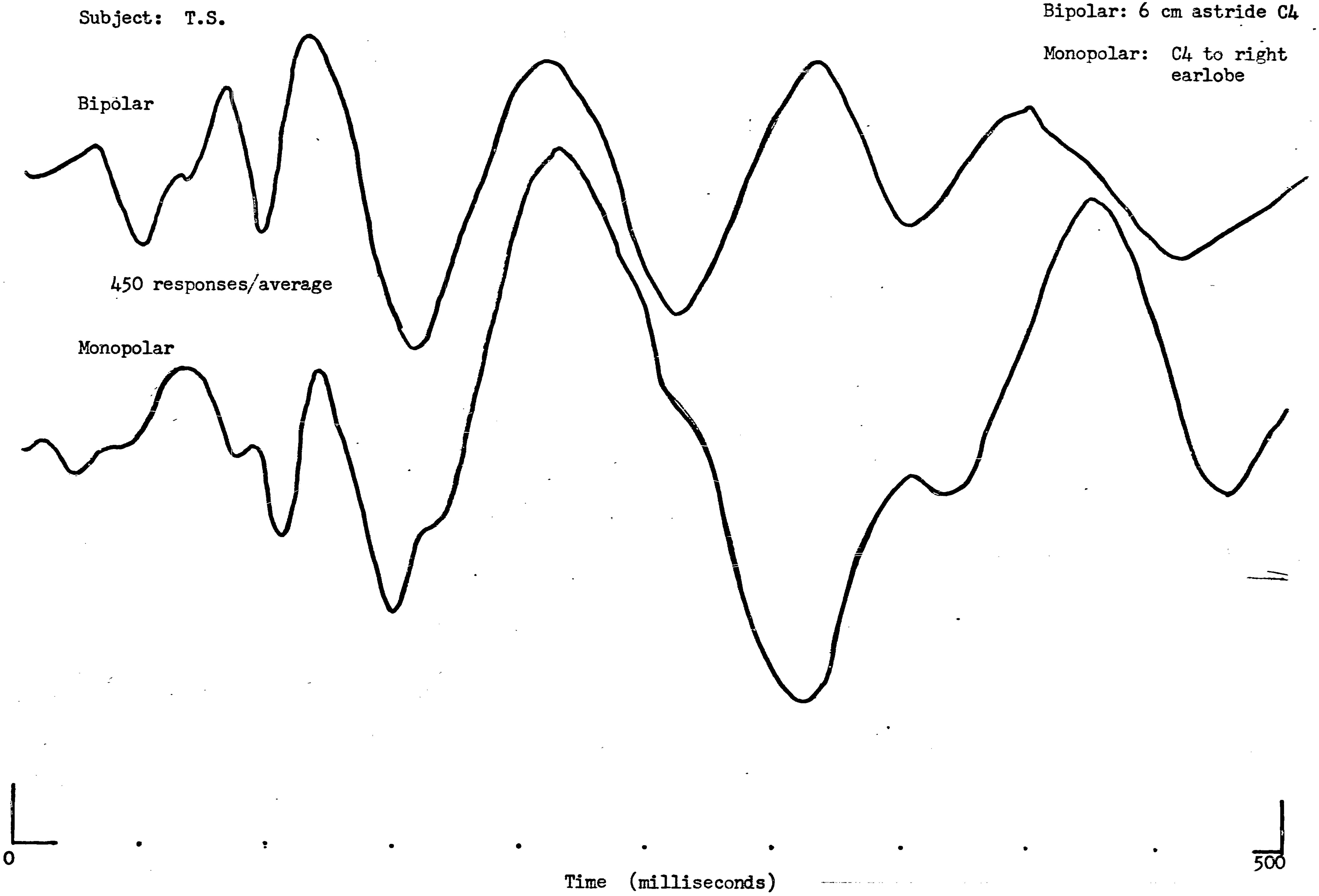
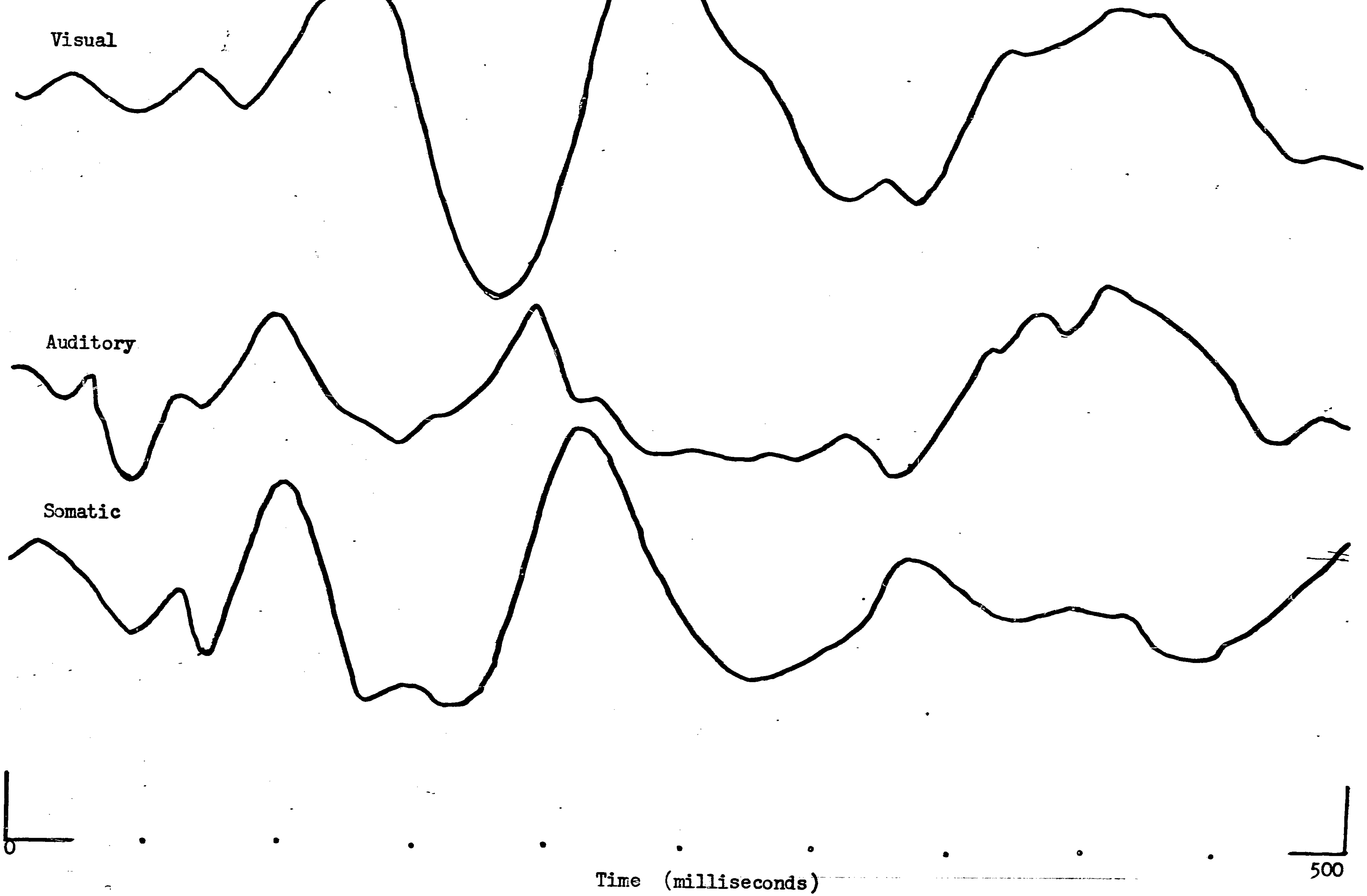


Figure 4

400 Responses Averaged

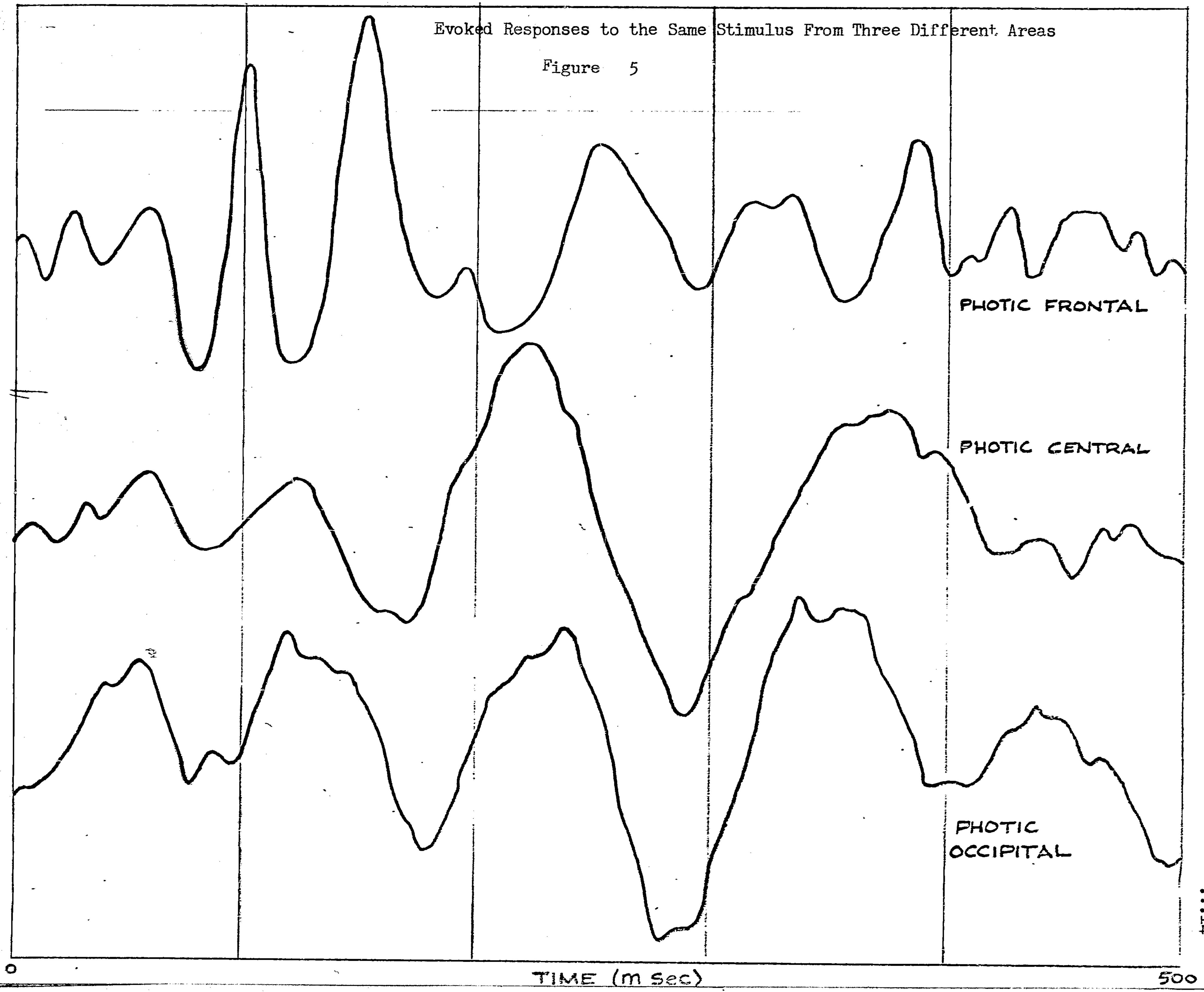
Subject: J.P.

EEG C3-A1, 3-50 Hz



Evoked Responses to the Same Stimulus From Three Different Areas

Figure 5



of wide spread application of this method, mono-polar electrode placements are much too sensitive in terms of exact location on the head.

We computed all relevant correlations anyway, and this is shown in Table II of Appendix A. As stated before, all correlations between EEG variables and between EEG variables psychological variables are meaningless. However, the intercorrelation between components of the visual evoked potential clearly show the unreliability problem. This is illustrated in Fig. 3 in which the 1968 bi-polar data is compared with the 1969 mono-polar data on the same subject. If proponents of the mono-polar electrode system were right, one would expect that the relationship between the first and second components of the VEP in a large sample of subjects would be at least as high as with the bi-polar system. It is, in fact, very significantly lower ($R = .59$, 1968: $R = .30$, 1969). In addition to this, it must be noted that the standard deviation of the second evoked potential component in the 1969 sample is 66.7 while it is only 15.8 in the 1968 sample. There is no apriori reason to expect such large differences and we can only interpret this as additional evidence of the unreliability of the mono-polar electrode system.

I(b). When the intercorrelation between psychological variables are considered (Table A ) we do get some small, but significant correlations between the Chopped Speech Test (CST) and I.Q. test scores. We have also obtained significant correlations with Academic Achievement (ACAV) and the CST. These correlations are certainly not high enough to indicate the discovery of a useful and quick test of intelligence. It is clear from Table A that, as expected, the intercorrelation between the three I.Q. tests is high and the correlation between academic achievement and the three I.Q. tests is also high. This simply indicates our confidence in the reliability of the psychometric data. Unfortunately, this can also be interpreted to mean that the three psychometric tests we have used, basically measure academic achievement.

II(a). A series of computer analyses of our criterion group of subjects drawn from the 1968 sample with bi-polar recordings was undertaken for the following reasons.

1) There have been three reports in the literature indicating substantial correlation between parameters of the evoked response and intelligence. In view of our tape library and facilities, we were in a position to attempt to corroborate these findings. The evoked potential parameters used by these three researchers (Dustman and Beck, 1969: Whittaker et al, 1967: Bennett, 1969) were different from our original work (Ertl, 1966), and we were hoping that the techniques used by these authors would also yield results with out data.

In the process of replicating the work of Dustman and Beck, our mathematical consultant Dr. O.R. Porebski developed a computer method

# TABLE A

| | AGE | WISC | OTIS | PMA | ACAV | CST |
|---|---|---|---|---|---|---|
| AGE | 1.00 | | | | | |
| WISC | .23 | 1.00 | | | | |
| OTIS | .17 | .59 | 1.00 | | | |
| PMA | .07 | .66 | .72 | 1.00 | | |
| ACAV | .35 | .58 | .64 | .62 | 1.00 | |
| CST | .05 | .14* | .23** | .19** | .16* | 1.00 |

** > .01

* > .05

for ordinary linear discriminant analysis in contrast with stepwise discriminant analysis as used by Dustman and Beck. This method has numerous advantages and is a more general form of discriminant analysis. Dr. Porebski has also developed time dependent discriminant analysis (Stanford University, 1970) which we plan to use in the near future. Basically, the amplitude of the evoked response at discrete time intervals is compared to intelligence. The first step following digital conversion of the data is to average the evoked response of the high I.Q. subjects together and the low I.Q. subjects together, this is shown in Fig. 6. It is obvious that there are substantial amplitude differences in the region 120 - 140 msec. between the high and low I.Q. groups. Following this, a procedure is adopted which will find the minimum number of amplitude values that maximaly discriminate the average waveforms of the high I.Q. group from the low I.Q. group. The results of discriminant analysis can be expressed as a correlation (Porebski, 1966) function, and when this is done with our sample of criterion subjects, the correlation increases from the -.35 reported for the entire sample (Ertl, 1969) to -.68. Our findings are only generally comparable with those of Dustman and Beck because their electrode placements, etc., were different, but we can corroborate the fact that the amplitude at certain time points of visual evoked response is greater for high I.Q. subjects than low.

We were unable to replicate the work of Whittaker, et al, using digital filtering technique described below. We measured the frequency of evoked response in narrow bands as reported by Whittaker and found no relationship with intelligence.

We also attempted to replicate the work of Bennett in which he claims that the "natural frequency of the dominant function is related to I.Q.". This natural frequency is equivalent (according to our consultant E.R. Funke) to the frequency in the Fourier transform with maximum amplitude. This measurement was available to us, but it did not correlate with intelligence, therefore, we can not corroborate the work of Bennett.

2) We also attempted analysis of our data using new parameters of the evoked response of our own invention. We report here results of the Fourier ratio analysis and the results of digital filtering. Many other methods were tried, they all failed, and are not considered a sufficient technical contribution to be reported here. The results with both the Fourier ratio analysis and digital filtering were borderline, but the techniques used are of considerable interest to workers in this field, and are, therefore, reported.

## Results of Fourier Ratio Analysis

Over the range of breakpoint frequencies examined, i.e., 11.7 to 44.9 Hz, one sub-range from 13.7 Hz to 17.6Hz yielded significant differences between mean Fourier Ratios (FR's) of high I.Q. and low I.Q. groups. Fig. 7 shows curves of mean FR vs. breakpoint frequency for

Figure 6

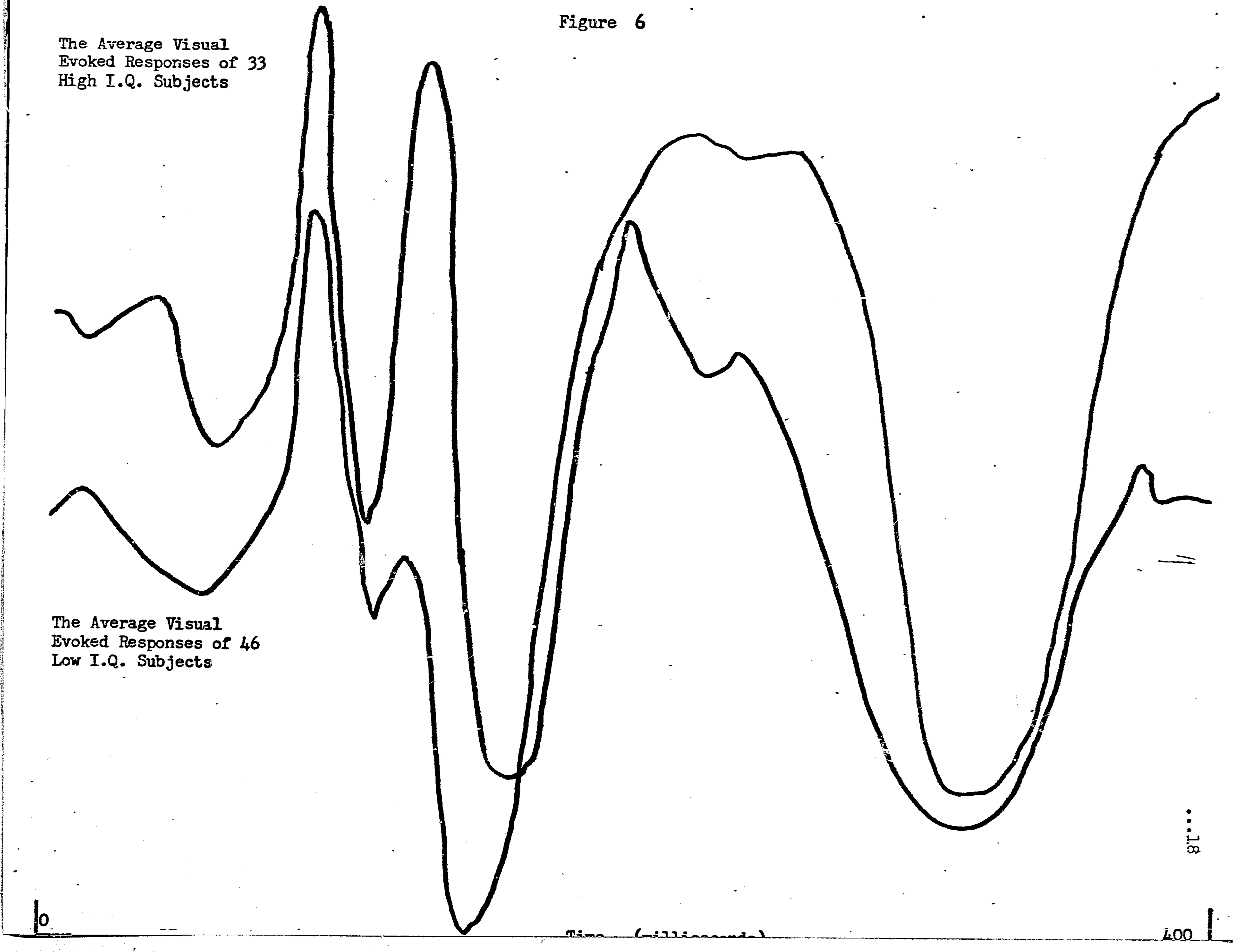
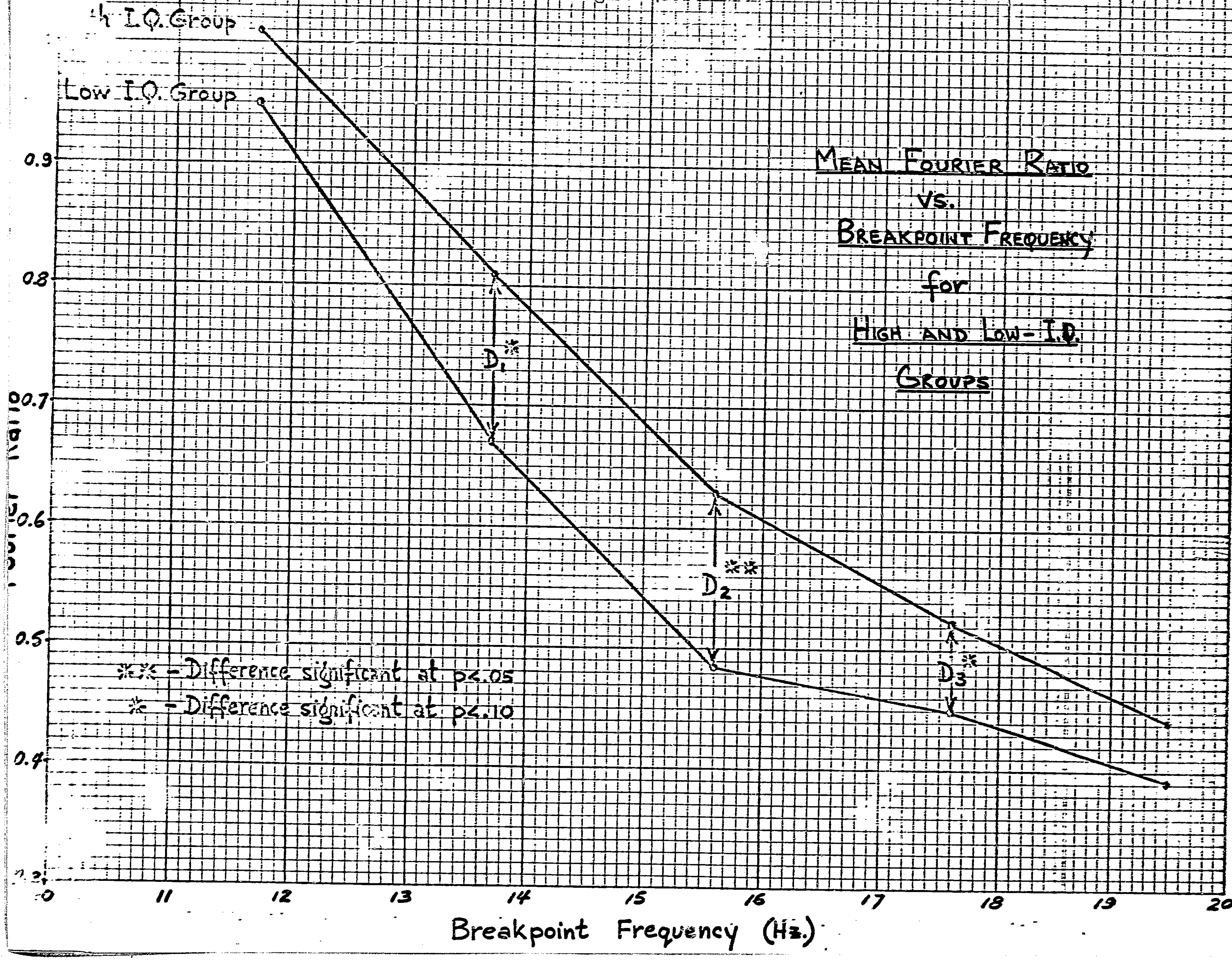

The Average Visual
Evoked Responses of 33
High I.Q. Subjects
The Average Visual
Evoked Responses of 46
Low I.Q. Subjects
0
400
Time (milliseconds)

Figure 7


MEAN FOURIER RATIO
VS.
BREAKPOINT FREQUENCY
for
HIGH AND LOW-I.Q.
GROUPS
High I.Q. Group
Low I.Q. Group
D1*
D2**
D3*
** - Difference significant at p<.05
* - Difference significant at p<.10
0.9
0.8
0.7
0.6
0.5
0.4
10
11
12
13
14
15
16
17
18
19
20
Breakpoint Frequency (Hz.)
IDEAL STATIONERY & OFFICE SUPPLY CO. LTD. 10 X 10

the two groups. The mean FR is significantly greater for high than for low I.Q. subjects in the vicinity of 15 Hz. In other words, the AEP frequency spectra of high and low I.Q. criterion subjects differ, in that the ratio of energy above a frequency of about 15 Hz to that below 15 Hz is greater for the high I.Q. subjects.

We have also attempted digital filtering of the data in various bandwidths. There were two reasons for this procedure:
i) to corroborate Whittaker
ii) to facilitate the zero crossing and peak distribution analysis by cleaning up the data as much as possible through filtering. Digital filtering has, of course, the advanatage of introducing no phase shifts and in this way we could evaluate the various filtering settings in the determination of evoked potential component latencies without making complex corrections for phase shifts. It is interesting to note that in this particular subject (Fig. 8 ) the evoked response has almost no energy content in the 8 - 12 Hz region, most of the energy is in the 1 - 8 Hz band closely followed by the 13 - 50 Hz band. This is not true for all subjects. Since digital filtering involves fourier analysis, we have a fourier analysis for all the criterion subjects and found that in general the frequency spectrum of the visual evoked response is quite similar from subject to subject, (a representative fourier spectrum is shown in Fig. 9 ). This being so, it is unlikely that any method (such as Whittaker and Bennett) which attempts to find differences in the frequency of evoked response in relation to intelligence is likely to succeed. We did not have time to fully evaluate the effect of digital filtering on our ability to determine evoked response component latencies using the zero crossing and peak distribution method. The preliminary indications are that it should be of considerable assistance.

3) We have greatly improved our original method of zero-crossing and peak distribution analysis from a technical point of view. The computer programs and techniques are of considerable interest, and are available to other researchers in the field.

A sample of our latest version of the zero-crossing and peak distribution analysis together with the fourier analysis is shown in computer read out, Table I , Appendix A . The headings of the various columns are self-explanatory. The present format is most useful in presenting maximum information, but is obviously far too complex when dealing with large samples. Considerable time and effort went into th preparation of this program and the feedback from the scientific community has been excellent in terms of the usefullness of this program.

II(b) 1) One of the principal aims of our study was to determine the predictive efficiency of evoked potential measures in relation to academic achievement scores. Table B illustrates these results. The Multiple R of .26 was obtained indicating that the present evoked potential measures are relatively poor predictors of academic achievement.

Effect of Digital Filtering on the Visual Evoked Response

Figure 8

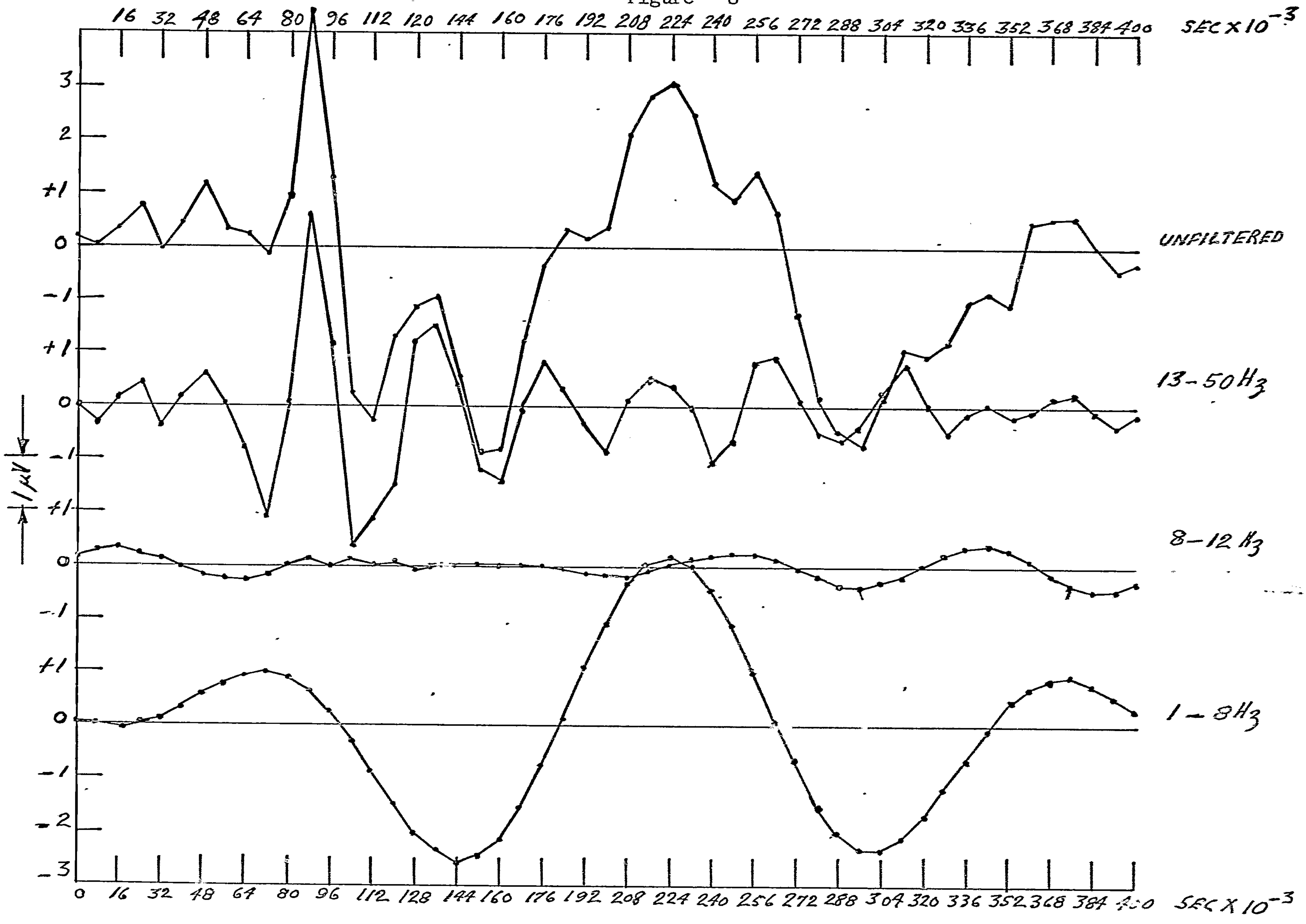
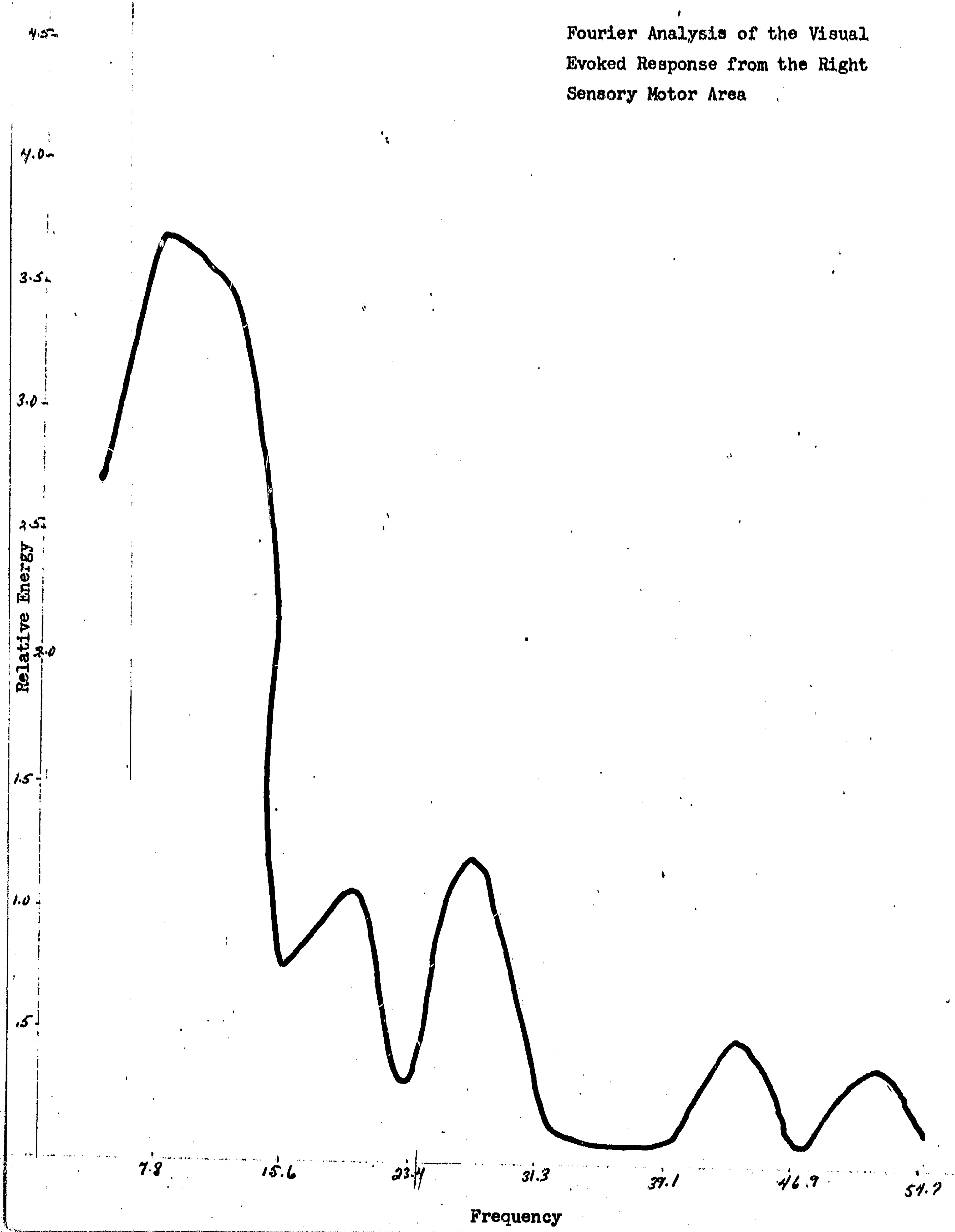


Figure 9

Fourier Analysis of the Visual Evoked Response from the Right Sensory Motor Area



## TABLE C

### Prediction of Academic Success From 3 I.Q. Tests

(N = 528)

| | PMA | WISC | OTIS | ACAV |
|---|---|---|---|---|
| PMA | 1.00 | 0.56 | 0.62 | 0.51 |
| WISC | 0.56 | 1.00 | 0.68 | 0.53 |
| OTIS | 0.62 | 0.68 | 1.00 | 0.48 |
| ACAV | 0.51 | 0.53 | 0.48 | 1.00 |
| MEANS | 104.95 | 105.05 | 100.23 | 70.29 |
| STANDARD DEVIATION | 13.98 | 14.08 | 14.68 | 11.64 |

MULTIPLE R = 0.5899557

## TABLE B

### Prediction of Academic Success From 4 Evoked Potential Measures

(N = 528)

Evoked Response Components

| | E1 | E2 | E3 | E4 | ACAV |
|---|---|---|---|---|---|
| E1 | 1.00 | 0.59 | 0.43 | 0.34 | -0.03 |
| E2 | 0.59 | 1.00 | 0.77 | 0.66 | -0.18 |
| E3 | 0.43 | 0.77 | 1.00 | 0.83 | -0.25 |
| E4 | 0.34 | 0.66 | 0.83 | 1.00 | -0.22 |
| ACAV | -0.03 | -0.18 | -0.25 | -0.22 | 1.00 |
| MEANS | 32.73 | 76.94 | 119.30 | 187.42 | 70.29 |
| STANDARD DEVIATION | 13.43 | 15.90 | 27.42 | 45.45 | 11.64 |

MULTIPLE R = 0.2628607

The predictive efficiency of I.Q. test scores in relation to academic achievement (Table C ) is much higher yielding a multiple R of .59. This is to be expected since in our opinion psychometric tests of intelligence are basically measures of academic achievement. These results, on first examination, may appear to be discouraging in terms of the practical usefullness of the evoked potential measures. However, an independent and valid criterion of human intelligence has not as yet been established and it is our hope that if such a measure is discovered, its relationship to evoked potential measures will be much better. The relatively high predictive efficiency of I.Q. test scores is probably due to the short time span of prediction. It is well known that the predictive efficiency of I.Q. test scores decreases as the time span is increased. We hope to be able to follow these subjects through the years and expect the predictive efficiency of the evoked potential measures to improve with time.

2) When we consider only the 79 criterion subjects, prediction of I.Q. from latency measures is very much improved yielding a multiple R of .68 (Table D ). Similarily, prediction of academic achievement from latency measures of this group increases to .6 (Table E). It is difficult to explain these results since, if the evoked potential measures were valid, there would be no reason to expect an improvement in predictive efficiency when dealing with the high and low I.Q. ranges. Since there is such a marked improvement, we have to conclude that it is the lack of validity of I.Q. tests, in the middle ranges of intelligence which cause the lowering of predictive efficiency of the evoked potential measures.

## TABLE D

Prediction of I.Q. From 3 Latency Measures

(N = 79)

| | E2 | E3 | E4 | I.Q. |
|---|---|---|---|---|
| E2 | 1.00 | 0.76 | 0.70 | -0.59 |
| E3 | 0.76 | 1.00 | 0.89 | -0.67 |
| E4 | 0.70 | 0.89 | 1.00 | -0.62 |
| I.Q. | -0.59 | -0.67 | -0.62 | 1.00 |
| MEANS | 73.73 | 117.15 | 186.84 | 0.58 |
| STANDARD DEVIATION | 18.66 | 40.34 | 65.23 | 0.50 |

MULTIPLE R = 0.6804271

# TABLE E

## Prediction of Academic Achievement From 3 Latency Measures

(N = 79)

| | E2 | E3 | E4 | ACAV |
|---|---|---|---|---|
| E2 | 1.00 | 0.76 | 0.70 | -0.53 |
| E3 | 0.76 | 1.00 | 0.89 | -0.59 |
| E4 | 0.70 | 0.89 | 1.00 | -0.50 |
| ACAV | -0.53 | -0.59 | -0.50 | 1.00 |
| MEANS | 73.73 | 117.15 | 186.84 | 71.57 |
| STANDARD DEVIATION | 18.66 | 40.34 | 65.23 | 15.57 |

MULTIPLE R = .6019522

## CONCLUSIONS

Neural efficiency in relation to human intelligence was the objective of this work. A significant and repeatable correlation between IQ test scores and parameters of the visual evoked potential in a sample of 573 children has been shown previously. (Ertl, 1969).

In this project we were hoping to demonstrate that the neural efficiency of the human brain as measured by certain parameters of sensory evoked potentials varies depending on the sensory input used within the same subject. We, therefore, stimulated visually, auditorally, and with a tactile stimulus, and analyzed the evoked responses from three different areas of the brain, frontal, central, and occipital. The subjects were 213 children aged 8 years to 16 years, selected randomly from our previous sample of 573.

Extensive computer analysis of the EEG data were performed in order to discover possible new parameters which are related to intelligence test scores.

By means of linear discriminant analysis, it was demonstrated that the amplitude of the visual evoked potential at certain time points following the stimulus is significantly greater for high IQ subjects. The results of the discriminant analysis are equivalent to a correlation co-efficiency of -.68. This procedure, therefore, substantially improves and objectifies the method when compared to earlier techniques. These results also confirm the work of Dustman and Beck.

By means of Fourier analysis, it was shown that there is a tendency for high IQ subjects to have greater energy above 14 cycles in their visual evoked response when compared to low IQ subjects. Predictions of academic achievement from evoked potential measures, though significant (.26), is poor when compared to predictions based on IQ test scores (.6). When predicting academic achievement from evoked potential measures using only the high and low IQ subjects, (N=79), the evoked potential predicts academic achievement equally as well as IQ test scores. All the above results were obtained with visual stimulation only. Unfortunately, due to unreliability of the evoked potential in response to auditory and tactile stimulation, we were unable to show any significant correlation with any variable in the study. This unreliability appears to be due to the particular electrode placement we have used and does not mean that the auditory and tactile evoked potentials are unreliable phenomena.

There is now little doubt that careful study of the electrical activity of the human brain can be related to intellectual functioning and continued exploration seems highly justified.

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# APPENDIX

# A

Table I

Appendix A

```
                                  PHASE 4A EVOKED RESPONSE ANALYSIS                           DATE OF ANALYSIS= 22 JUL.196
*************************************************************************************************************************
**                                  USOE SUBJECT NO.=      89                                                            *
**                                                                                                                       *
**      TEST INFORMATION                                                       SUBJECT INFORMATION                       *
**                                                                                                                       *
**   STIMULUS MODALITY = VISUAL                                            SEX        = F                                *
**   ELECTRODE LOCATION= L CENTRAL                                         AGE        = 103 MONTHS                       *
**   NO. OF STIMULI     = 375                                              PMA  I.Q.= 119                                *
**   NO. OF SAMPLES PER STIMULUS= 101                                      WISC I.Q.= 115                                *
**   SAMPLE INTERVAL    = 4 MILLISECONDS                                   OTIS I.Q.= 134                                *
**   PREFILTERING       = TYPE  1                                                                                        *
**   AMPLIFICATION      = 0.400E 05                                                                                      *
**   ATTENUATION        = 1.000                                                                                          *
**   CONVERSION PRECISION =  6 BIT                                                                                       *
**   TEST DATE          = 01 03 68                                                                                       *
**   TEST LOCATION      = OTTAWA                                                                                         *
**                                                                                                                       *
*************************************************************************************************************************

                                   SUMMARY OF ANALYSIS RESULTS

*************************************************************************************************************************
**                             MEAN OF AVERAGE EVOKED RESPONSE =-0.38241E-06 VOLTS                                       *
**                             RMS OF AVERAGE EVOKED RESPONSE  = 0.18646E-05 VOLTS                                       *
**                             CHANNEL WIDTH FOR ANALYSIS      =    4 MILLISECONDS                                       *
**                                                                                                                       *
**        ZERC CROSSING INFORMATION                                        PEAK AND TROUGH INFORMATION                   *
**    MEAN NO. OF FALLING ZEROS/CHANNEL= 24.97                          MEAN NO. OF PEAKS/CHANNEL   =  45.41             *
**    MEAN NO. OF LEADING ZEROS/CHANNEL= 25.54                          MEAN NO. OF TROUGHS/CHANNEL=  45.34              *
**                                                                                                                       *
**    POISSON CRITICAL COUNTS...                                        POISSON CRITICAL COUNTS...                       *
**                FALLING   LEADING FALLING-LEADING                                   PEAKS    TROUGHS   PEAKS-TROUGHS   *
**          .010 *  36.62  *  37.33  *           *                           .010 *  61.11  *  61.03  *          *       *
**    UPPER .025 *  34.78  *  35.46  *    18.07  * .010                UPPER .025 *  58.63  *  58.55  *   24.22  * .010  *
**          .050 *  33.21  *  33.87  *           *                           .050 *  56.51  *  56.43  *          *       *
**               *         *         *    15.57  * .025                           *         *         *   20.87  * .025  *
**          .010 *  13.32  *  13.76  *           *                           .010 *  29.70  *  29.64  *          *       *
**    LOWER .025 *  15.16  *  15.62  *    13.54  * .050                LOWER .025 *  32.18  *  32.12  *   18.15  * .050  *
**          .050 *  16.74  *  17.22  *           *                           .050 *  34.30  *  34.24  *          *       *
**                                                                                                                       *
*************************************************************************************************************************
```

```
                                  AVERAGE EVOKED RESPONSE                                         FOURIER ANALYSIS
  MSEC      SCALE FACTOR# 0.19616E-06 VOLTS/DIVISION           AMPLITUDE           FREQUENCY      AMPLITUDE       PHASE
      11111111111111111111111111111111111111111111111111
     0 1    1    1    1    1 *  1    1    1    1    1      -0.57916E-06       0.0            0.38241E-06    0.0
     4                        * 1                          -0.38333E-06       0.19531E 01    0.42511E-06   -0.28270E 02
     8                        * 1                          -0.39791E-06       0.39062E 01    0.34849E-06   -0.10341E 03
    12                        * 1                          -0.52291E-06       0.58594E 01    0.88982E-06    0.16317E 03
    16                       *  1                          -0.72497E-06       0.78125E 01    0.10568E-05   -0.16518E 01
    20 1    1    1    1    1*   1    1    1    1    1      -0.87078E-06       0.97656E 01    0.17418E-06    0.13422E 03
    24                       *  1                          -0.71456E-06       0.11719E 02    0.12178E-05   -0.16258E 03
    28                         *1                          -0.25416E-06       0.13672E 02    0.92208E-06   -0.41987E 02
1   32                          1*                          0.16042E-06       0.15625E 02    0.10820E-05    0.37811E 02
    36                          1 *                         0.32291E-06       0.17578E 02    0.86018E-06    0.13738E 03
    40 1    1    1    1    1    *    1    1    1    1      -0.75001E-07       0.19531E 02    0.86423E-06   -0.13799E 03
    44                       *  1                          -0.69999E-06       0.21484E 02    0.55689E-06   -0.83098E 02
    48                      *   1                          -0.92496E-06       0.23438E 02    0.54793E-06    0.73297E 01
    52                      *   1                          -0.77914E-06       0.25391E 02    0.37961E-06    0.65770E 02
    56                        * 1                          -0.45624E-06       0.27344E 02    0.13201E-06   -0.16533E 03
2   60 1    1    1    1    1    *    1    1    1    1      -0.10208E-06       0.29297E 02    0.32244E-06   -0.16365E 03
    64                          1*                          0.68747E-07       0.31250E 02    0.25091E-06   -0.71240E 02
    68                          *                           0.31251E-07       0.33203E 02    0.42824E-06    0.18501E 02
    72                          1*                          0.66665E-07       0.35156E 02    0.19666E-06    0.90883E 02
    76                          1  *                        0.48958E-06       0.37109E 02    0.16878E-06    0.16784E 03
    80 1    1    1    1    1    1    1*   1    1    1       0.11958E-05       0.39063E 02    0.11050E-06   -0.15085E 03
3   84                          1       *                   0.15208E-05       0.41016E 02    0.89302E-07    0.10867E 03
    88                          1     *                     0.10499E-05       0.42969E 02    0.92417E-08   -0.12434E 02
    92                         *1                          -0.19792E-06       0.44922E 02    0.81992E-07   -0.13996E 03
    96                *         1                          -0.19999E-05       0.46875E 02    0.79726E-07   -0.88163E 02
   100 1    1*   1    1    1    1    1    1    1    1      -0.38541E-05       0.48828E 02    0.74080E-07   -0.16067E 03
   104 *                        1                          -0.50478E-05       0.50781E 02    0.84160E-07    0.72623E 02
   108 *                        1                          -0.48957E-05       0.52734E 02    0.63213E-07   -0.28065E 02
   112          *               1                          -0.31353E-05       0.54688E 02    0.57366E-07   -0.12874E 03
   116                         *1                          -0.23541E-06
   120 1    1    1    1    1    1    1    1  * 1    1       0.25770E-05
   124                          1                     *     0.43457E-05
4  128                          1                       *   0.47603E-05
   132                          1                     *     0.42936E-05
   136                          1                *          0.33686E-05
   140 1    1    1    1    1    1    1    1 *  1    1       0.23582E-05
   144                          1      *                    0.13562E-05
   148                          1 *                         0.25833E-06
   152                     *    1                          -0.10395E-05
   156             *            1                          -0.25270E-05
   160 1    1*   1    1    1    1    1    1    1    1      -0.37916E-05
   164    *                     1                          -0.44437E-05
   168    *                     1                          -0.43520E-05
   172       *                  1                          -0.37291E-05
```

```
180 1    1    1   *1    1    1    1    1    1    1     -0.21207E-05
184                  *       1                         -0.16582E-05
188                    *     1                         -0.12812E-05
192                     *    1                         -0.97074E-06
196                       *  1                         -0.71244E-06
200 1    1    1    1    1  * 1    1    1    1    1     -0.36249E-06
204                          1*                         0.19583E-06
208                          1   *                      0.72289E-06
212                          1    *                     0.85620E-06
216                          1   *                      0.67082E-06
220 1    1    1    1    1    1 *  1    1    1    1      0.42499E-06
224                          1*                         0.10417E-06
228                         *1                         -0.16041E-06
232                         *1                         -0.24374E-06
236                          *                         -0.13542E-06
240 1    1    1    1    1    1*   1    1    1    1      0.17499E-06
244                          1  *                       0.56454E-06
248                          1  *                       0.62079E-06
252                          1  *                       0.52914E-06
256                          1 *                        0.41666E-06
260 1    1    1    1    1    1 *  1    1    1    1      0.27083E-06
264                          *                         -0.13750E-06
268                         *1                         -0.33333E-06
272                          *                         -0.13958E-06
276                          1*                         0.13125E-06
280 1    1    1    1    1    1*   1    1    1    1      0.10209E-06
284                         *1                         -0.25624E-06
288                        * 1                         -0.46874E-06
292                        * 1                         -0.48958E-06
296                        * 1                         -0.34583E-06
300 1    1    1    1    1  * 1    1    1    1    1     -0.51457E-06
304                     *    1                         -0.93535E-06
308                   *      1                         -0.14999E-05
312                 *        1                         -0.18082E-05
316                 *        1                         -0.18374E-05
320 1    1    1    *    1    1    1    1    1    1     -0.19311E-05
324                *         1                         -0.21499E-05
328               *          1                         -0.24311E-05
332              *           1                         -0.26020E-05
336              *           1                         -0.25124E-05
340 1    1    1  * 1    1    1    1    1    1    1     -0.23187E-05
344                *         1                         -0.21291E-05
348                 *        1                         -0.17728E-05
352                   *      1                         -0.13312E-05
356                      *   1                         -0.79166E-06
360 1    1    1    1    1   *1    1    1    1    1     -0.23750E-06
364                          1*                         0.89577E-07
368                          1*                         0.16458E-06
372                          1 *                        0.35207E-06
376                          1   *                      0.82077E-06
```

| LATNCY MS. | FALNG ZERO | SIGNF | LDNG ZERO | SIGNF | PEAKS | SIGNF | TRGHS | SIGNF | F-L ZEROS | SIGNF | PKS-TRGHS | SIGNF | LATNCY MS. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4 | 27 | 0.0 | 23 | 0.0 | 56 | 0.0 | 51 | 0.0 | 4 | 0.0 | 5 | 0.0 | 4 |
| 8 | 24 | 0.0 | 25 | 0.0 | 52 | 0.0 | 39 | 0.0 | -1 | 0.0 | 13 | 0.0 | 8 |
| 12 | 22 | 0.0 | 29 | 0.0 | 53 | 0.0 | 50 | 0.0 | -7 | 0.0 | 3 | 0.0 | 12 |
| 16 | 28 | 0.0 | 20 | 0.0 | 44 | 0.0 | 54 | 0.0 | 8 | 0.0 | -10 | 0.0 | 16 |
| 20 | 30 | 0.0 | 29 | 0.0 | 46 | 0.0 | 58 | 0.050 | 1 | 0.0 | -12 | 0.0 | 20 |
| 24 | 20 | 0.0 | 33 | 0.0 | 37 | 0.0 | 58 | 0.050 | -13 | 0.0 | -21 | -0.025 | 24 |
| 28 | 25 | 0.0 | 27 | 0.0 | 52 | 0.0 | 45 | 0.0 | -2 | 0.0 | 7 | 0.0 | 28 |
| 32 | 24 | 0.0 | 28 | 0.0 | 64 | 0.010 | 41 | 0.0 | -4 | 0.0 | 23 | 0.025 | 32 |
| 36 | 30 | 0.0 | 24 | 0.0 | 66 | 0.010 | 35 | 0.0 | 6 | 0.0 | 31 | 0.010 | 36 |
| 40 | 23 | 0.0 | 15 | -0.025 | 45 | 0.0 | 48 | 0.0 | 8 | 0.0 | -3 | 0.0 | 40 |
| 44 | 26 | 0.0 | 22 | 0.0 | 45 | 0.0 | 54 | 0.0 | 4 | 0.0 | -9 | 0.0 | 44 |
| 48 | 28 | 0.0 | 26 | 0.0 | 39 | 0.0 | 57 | 0.050 | 2 | 0.0 | -18 | -0.050 | 48 |
| 52 | 17 | -0.050 | 22 | 0.0 | 49 | 0.0 | 54 | 0.0 | -5 | 0.0 | -5 | 0.0 | 52 |
| 56 | 22 | 0.0 | 26 | 0.0 | 44 | 0.0 | 54 | 0.0 | -4 | 0.0 | -10 | 0.0 | 56 |
| 60 | 22 | 0.0 | 35 | 0.025 | 62 | 0.010 | 51 | 0.0 | -13 | 0.0 | 11 | 0.0 | 60 |
| 64 | 34 | 0.050 | 26 | 0.0 | 56 | 0.0 | 45 | 0.0 | 8 | 0.0 | 11 | 0.0 | 64 |
| 68 | 27 | 0.0 | 30 | 0.0 | 49 | 0.0 | 47 | 0.0 | -3 | 0.0 | 2 | 0.0 | 68 |
| 72 | 23 | 0.0 | 29 | 0.0 | 41 | 0.0 | 55 | 0.0 | -6 | 0.0 | -14 | 0.0 | 72 |
| 76 | 28 | 0.0 | 28 | 0.0 | 47 | 0.0 | 56 | 0.050 | 0 | 0.0 | -9 | 0.0 | 76 |
| 80 | 19 | 0.0 | 41 | 0.010 | 46 | 0.0 | 38 | 0.0 | -22 | -0.010 | 8 | 0.0 | 80 |
| 84 | 28 | 0.0 | 24 | 0.0 | 63 | 0.010 | 33 | -0.050 | 4 | 0.0 | 30 | 0.010 | 84 |
| 88 | 37 | 0.010 | 15 | -0.025 | 61 | 0.010 | 36 | 0.0 | 22 | 0.010 | 25 | 0.010 | 88 |
| 92 | 41 | 0.010 | 19 | 0.0 | 53 | 0.0 | 21 | -0.010 | 22 | 0.010 | 32 | 0.010 | 92 |
| 96 | 37 | 0.010 | 9 | -0.010 | 32 | -0.025 | 36 | 0.0 | 28 | 0.010 | -4 | 0.0 | 96 |
| 100 | 46 | 0.010 | 10 | -0.010 | 25 | -0.010 | 60 | 0.025 | 36 | 0.010 | -35 | -0.010 | 100 |
| 104 | 21 | 0.0 | 24 | 0.0 | 27 | -0.010 | 66 | 0.010 | -3 | 0.0 | -39 | -0.010 | 104 |
| 108 | 12 | -0.010 | 24 | 0.0 | 17 | -0.010 | 97 | 0.010 | -12 | 0.0 | -80 | -0.010 | 108 |
| 112 | 9 | -0.010 | 41 | 0.010 | 22 | -0.010 | 57 | 0.050 | -32 | -0.010 | -35 | -0.010 | 112 |
| 116 | 12 | -0.010 | 70 | 0.010 | 30 | -0.010 | 30 | -0.010 | -58 | -0.010 | 0 | 0.0 | 116 |
| 120 | 10 | -0.010 | 51 | 0.010 | 55 | 0.0 | 19 | -0.010 | -41 | -0.010 | 36 | 0.010 | 120 |
| 124 | 11 | -0.010 | 28 | 0.0 | 81 | 0.010 | 22 | -0.010 | -17 | -0.025 | 59 | 0.010 | 124 |
| 128 | 22 | 0.0 | 16 | -0.025 | 71 | 0.010 | 24 | -0.010 | 6 | 0.0 | 47 | 0.010 | 128 |
| 132 | 22 | 0.0 | 14 | -0.010 | 49 | 0.0 | 38 | 0.0 | 8 | 0.0 | 11 | 0.0 | 132 |
| 136 | 34 | 0.050 | 15 | -0.025 | 45 | 0.0 | 31 | -0.025 | 19 | 0.010 | 14 | 0.0 | 136 |
| 140 | 28 | 0.0 | 13 | -0.010 | 41 | 0.0 | 38 | 0.0 | 15 | 0.050 | 3 | 0.0 | 140 |
| 144 | 25 | 0.0 | 16 | -0.025 | 37 | 0.0 | 36 | 0.0 | 9 | 0.0 | 1 | 0.0 | 144 |
| 148 | 28 | 0.0 | 9 | -0.010 | 42 | 0.0 | 29 | -0.010 | 19 | 0.010 | 13 | 0.0 | 148 |
| 152 | 39 | 0.010 | 9 | -0.010 | 37 | 0.0 | 21 | -0.010 | 30 | 0.010 | 16 | 0.0 | 152 |
| 156 | 39 | 0.010 | 10 | -0.010 | 23 | -0.010 | 50 | 0.0 | 29 | 0.010 | -27 | -0.010 | 156 |
| 160 | 34 | 0.050 | 12 | -0.010 | 33 | -0.050 | 58 | 0.050 | 22 | 0.010 | -25 | -0.010 | 160 |
| 164 | 24 | 0.0 | 13 | -0.010 | 25 | -0.010 | 55 | 0.0 | 11 | 0.0 | -30 | -0.010 | 164 |
| 168 | 17 | -0.050 | 25 | 0.0 | 32 | -0.025 | 58 | 0.050 | -8 | 0.0 | -26 | -0.010 | 168 |
| 172 | 14 | -0.025 | 26 | 0.0 | 37 | 0.0 | 49 | 0.0 | -12 | 0.0 | -12 | 0.0 | 172 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 184 | 16 | -0.050 | 31 | 0.0 | 51 | 0.0 | 42 | 0.0 |
| 188 | 24 | 0.0 | 26 | 0.0 | 49 | 0.0 | 48 | 0.0 |
| 192 | 18 | 0.0 | 27 | 0.0 | 52 | 0.0 | 42 | 0.0 |
| 196 | 13 | -0.010 | 33 | 0.0 | 47 | 0.0 | 49 | 0.0 |
| 200 | 32 | 0.0 | 31 | 0.0 | 50 | 0.0 | 49 | 0.0 |
| 204 | 29 | 0.0 | 29 | 0.0 | 42 | 0.0 | 51 | 0.0 |
| 208 | 23 | 0.0 | 25 | 0.0 | 60 | 0.025 | 40 | 0.0 |
| 212 | 21 | 0.0 | 24 | 0.0 | 53 | 0.0 | 49 | 0.0 |
| 216 | 35 | 0.025 | 35 | 0.025 | 46 | 0.0 | 46 | 0.0 |
| 220 | 33 | 0.050 | 26 | 0.0 | 44 | 0.0 | 39 | 0.0 |
| 224 | 23 | 0.0 | 23 | 0.0 | 53 | 0.0 | 50 | 0.0 |
| 228 | 24 | 0.0 | 23 | 0.0 | 45 | 0.0 | 47 | 0.0 |
| 232 | 30 | 0.0 | 35 | 0.025 | 42 | 0.0 | 58 | 0.050 |
| 236 | 29 | 0.0 | 34 | 0.050 | 40 | 0.0 | 53 | 0.0 |
| 240 | 29 | 0.0 | 27 | 0.0 | 53 | 0.0 | 40 | 0.0 |
| 244 | 32 | 0.0 | 32 | 0.0 | 46 | 0.0 | 44 | 0.0 |
| 248 | 28 | 0.0 | 24 | 0.0 | 57 | 0.050 | 51 | 0.0 |
| 252 | 28 | 0.0 | 25 | 0.0 | 57 | 0.050 | 57 | 0.050 |
| 256 | 26 | 0.0 | 27 | 0.0 | 44 | 0.0 | 40 | 0.0 |
| 260 | 29 | 0.0 | 30 | 0.0 | 43 | 0.0 | 45 | 0.0 |
| 264 | 24 | 0.0 | 26 | 0.0 | 47 | 0.0 | 45 | 0.0 |
| 268 | 30 | 0.0 | 29 | 0.0 | 41 | 0.0 | 54 | 0.0 |
| 272 | 29 | 0.0 | 31 | 0.0 | 59 | 0.025 | 48 | 0.0 |
| 276 | 24 | 0.0 | 27 | 0.0 | 45 | 0.0 | 44 | 0.0 |
| 280 | 30 | 0.0 | 26 | 0.0 | 55 | 0.0 | 47 | 0.0 |
| 284 | 31 | 0.0 | 24 | 0.0 | 38 | 0.0 | 52 | 0.0 |
| 288 | 27 | 0.0 | 26 | 0.0 | 44 | 0.0 | 53 | 0.0 |
| 292 | 29 | 0.0 | 31 | 0.0 | 54 | 0.0 | 49 | 0.0 |
| 296 | 26 | 0.0 | 26 | 0.0 | 50 | 0.0 | 38 | 0.0 |
| 300 | 31 | 0.0 | 24 | 0.0 | 46 | 0.0 | 36 | 0.0 |
| 304 | 34 | 0.050 | 16 | -0.025 | 54 | 0.0 | 43 | 0.0 |
| 308 | 34 | 0.050 | 24 | 0.0 | 35 | 0.0 | 64 | 0.010 |
| 312 | 27 | 0.0 | 28 | 0.0 | 43 | 0.0 | 40 | 0.0 |
| 316 | 28 | 0.0 | 24 | 0.0 | 47 | 0.0 | 52 | 0.0 |
| 320 | 24 | 0.0 | 27 | 0.0 | 60 | 0.025 | 46 | 0.0 |
| 324 | 22 | 0.0 | 22 | 0.0 | 48 | 0.0 | 46 | 0.0 |
| 328 | 26 | 0.0 | 21 | 0.0 | 47 | 0.0 | 46 | 0.0 |
| 332 | 24 | 0.0 | 22 | 0.0 | 37 | 0.0 | 53 | 0.0 |
| 336 | 22 | 0.0 | 29 | 0.0 | 35 | 0.0 | 43 | 0.0 |
| 340 | 24 | 0.0 | 33 | 0.0 | 48 | 0.0 | 44 | 0.0 |
| 344 | 21 | 0.0 | 24 | 0.0 | 43 | 0.0 | 48 | 0.0 |
| 348 | 25 | 0.0 | 26 | 0.0 | 41 | 0.0 | 53 | 0.0 |
| 352 | 16 | -0.050 | 21 | 0.0 | 50 | 0.0 | 49 | 0.0 |
| 356 | 29 | 0.0 | 30 | 0.0 | 44 | 0.0 | 44 | 0.0 |
| 360 | 19 | 0.0 | 38 | 0.010 | 41 | 0.0 | 29 | -0.010 |
| 364 | 16 | -0.050 | 23 | 0.0 | 55 | 0.0 | 52 | 0.0 |
| 368 | 24 | 0.0 | 36 | 0.025 | 45 | 0.0 | 47 | 0.0 |
| 372 | 21 | 0.0 | 25 | 0.0 | 46 | 0.0 | 56 | 0.050 |
| 376 | 25 | 0.0 | 24 | 0.0 | 44 | 0.0 | 49 | 0.0 |
| 380 | 23 | 0.0 | 28 | 0.0 | | | | |

| | | | | |
|---|---|---|---|---|
| -14 | -0.050 | 4 | 0.0 | 180 |
| -15 | -0.050 | 9 | 0.0 | 184 |
| -2 | 0.0 | 1 | 0.0 | 188 |
| -9 | 0.0 | 10 | 0.0 | 192 |
| -20 | -0.010 | -2 | 0.0 | 196 |
| 1 | 0.0 | 1 | 0.0 | 200 |
| 0 | 0.0 | -9 | 0.0 | 204 |
| -2 | 0.0 | 20 | 0.050 | 208 |
| -3 | 0.0 | 4 | 0.0 | 212 |
| 0 | 0.0 | 0 | 0.0 | 216 |
| 7 | 0.0 | 5 | 0.0 | 220 |
| 0 | 0.0 | 3 | 0.0 | 224 |
| 1 | 0.0 | -2 | 0.0 | 228 |
| -5 | 0.0 | -16 | 0.0 | 232 |
| -5 | 0.0 | -13 | 0.0 | 236 |
| 2 | 0.0 | 13 | 0.0 | 240 |
| 0 | 0.0 | 2 | 0.0 | 244 |
| 4 | 0.0 | 6 | 0.0 | 248 |
| 3 | 0.0 | 0 | 0.0 | 252 |
| -1 | 0.0 | 4 | 0.0 | 256 |
| -1 | 0.0 | -2 | 0.0 | 260 |
| -2 | 0.0 | 2 | 0.0 | 264 |
| 1 | 0.0 | -13 | 0.0 | 268 |
| -2 | 0.0 | 11 | 0.0 | 272 |
| -3 | 0.0 | 1 | 0.0 | 276 |
| 4 | 0.0 | 8 | 0.0 | 280 |
| 7 | 0.0 | -14 | 0.0 | 284 |
| 1 | 0.0 | -9 | 0.0 | 288 |
| -2 | 0.0 | 5 | 0.0 | 292 |
| 0 | 0.0 | 12 | 0.0 | 296 |
| 7 | 0.0 | 10 | 0.0 | 300 |
| 18 | 0.010 | 11 | 0.0 | 304 |
| 10 | 0.0 | -29 | -0.010 | 308 |
| -1 | 0.0 | 3 | 0.0 | 312 |
| 4 | 0.0 | -5 | 0.0 | 316 |
| -3 | 0.0 | 14 | 0.0 | 320 |
| 0 | 0.0 | 2 | 0.0 | 324 |
| 5 | 0.0 | 1 | 0.0 | 328 |
| 2 | 0.0 | -16 | 0.0 | 332 |
| -7 | 0.0 | -8 | 0.0 | 336 |
| -9 | 0.0 | 4 | 0.0 | 340 |
| -3 | 0.0 | -5 | 0.0 | 344 |
| -1 | 0.0 | -12 | 0.0 | 348 |
| -5 | 0.0 | 1 | 0.0 | 352 |
| -1 | 0.0 | 0 | 0.0 | 356 |
| -19 | -0.010 | 12 | 0.0 | 360 |
| -7 | 0.0 | 3 | 0.0 | 364 |
| -12 | 0.0 | -2 | 0.0 | 368 |
| -4 | 0.0 | -10 | 0.0 | 372 |
| 1 | 0.0 | -5 | 0.0 | 376 |

## Table II CORRELATION MATRIX

Anpend

|  | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 1 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | AGE | WISC | OTIS | PMA | ACHV | CST | PF1 | PF2 | PF3 | PF4 | PC1 | PC2 | PC3 | PC4 | PO1 | PO2 | PO |
| 1 | 1.00 | -0.23 | -0.17 | -0.07 | -0.35 | 0.05 | 0.06 | -0.06 | -0.04 | -0.01 | -0.14 | -0.07 | -0.11 | -0.07 | -0.14 | -0.07 | -0.1 |
| 2 | -0.23 | 1.00 | 0.59 | 0.66 | 0.58 | 0.14 | -0.10 | 0.04 | -0.04 | -0.04 | -0.02 | 0.06 | 0.02 | -0.02 | -0.00 | 0.05 | -0.0 |
| 3 | -0.17 | 0.59 | 1.00 | 0.72 | 0.64 | 0.23 | -0.13 | 0.04 | -0.04 | 0.02 | 0.02 | 0.06 | -0.05 | -0.11 | 0.11 | 0.11 | 0.0 |
| 4 | -0.07 | 0.66 | 0.72 | 1.00 | 0.62 | 0.19 | -0.10 | -0.03 | -0.11 | -0.07 | -0.01 | 0.01 | -0.12 | -0.13 | -0.03 | 0.02 | -0.0 |
| 5 | -0.35 | 0.58 | 0.64 | 0.62 | 1.00 | 0.16 | -0.11 | 0.06 | -0.05 | -0.01 | 0.03 | 0.08 | -0.03 | -0.09 | 0.04 | 0.08 | 0.0 |
| 6 | 0.05 | 0.14 | 0.23 | 0.19 | 0.16 | 1.00 | -0.01 | 0.01 | -0.02 | -0.00 | 0.02 | -0.02 | -0.14 | -0.15 | -0.05 | -0.02 | -0.1 |
| 7 | 0.06 | -0.10 | -0.13 | -0.10 | -0.11 | -0.01 | 1.00 | 0.40 | 0.46 | 0.40 | -0.04 | -0.01 | -0.00 | -0.00 | 0.06 | -0.00 | 0.0 |
| 8 | -0.06 | 0.04 | 0.04 | -0.03 | 0.06 | 0.01 | 0.40 | 1.00 | 0.34 | 0.69 | 0.04 | 0.77 | 0.35 | 0.13 | 0.10 | 0.75 | 0.3 |
| 9 | -0.04 | -0.04 | -0.04 | -0.11 | -0.05 | -0.02 | 0.46 | 0.34 | 1.00 | 0.76 | 0.06 | -0.08 | 0.13 | 0.15 | 0.16 | -0.12 | -0.0 |
| 10 | -0.01 | -0.04 | 0.02 | -0.07 | -0.01 | -0.00 | 0.40 | 0.69 | 0.76 | 1.00 | 0.04 | 0.38 | 0.25 | 0.15 | 0.14 | 0.34 | 0.1 |
| 11 | -0.14 | -0.02 | 0.02 | -0.01 | 0.03 | 0.02 | -0.04 | 0.04 | 0.06 | 0.04 | 1.00 | 0.30 | 0.47 | 0.43 | 0.22 | 0.17 | 0.2 |
| 12 | -0.07 | 0.06 | 0.06 | 0.01 | 0.08 | -0.02 | -0.01 | 0.77 | -0.08 | 0.38 | 0.30 | 1.00 | 0.64 | 0.39 | 0.09 | 0.87 | 0.4 |
| 13 | -0.11 | 0.02 | -0.05 | -0.12 | -0.03 | -0.14 | -0.00 | 0.35 | 0.13 | 0.25 | 0.47 | 0.64 | 1.00 | 0.91 | 0.18 | 0.41 | 0.3 |
| 14 | -0.07 | -0.02 | -0.11 | -0.13 | -0.09 | -0.15 | -0.00 | 0.13 | 0.15 | 0.15 | 0.43 | 0.39 | 0.91 | 1.00 | 0.14 | 0.15 | 0.2 |
| 15 | -0.14 | -0.00 | 0.11 | -0.03 | 0.04 | -0.05 | 0.06 | 0.10 | 0.16 | 0.14 | 0.22 | 0.09 | 0.18 | 0.14 | 1.00 | 0.32 | 0.6 |
| 16 | -0.07 | 0.05 | 0.11 | 0.02 | 0.08 | -0.02 | -0.00 | 0.75 | -0.12 | 0.34 | 0.12 | 0.87 | 0.41 | 0.15 | 0.32 | 1.00 | 0.7 |
| 17 | -0.14 | -0.06 | 0.04 | -0.07 | 0.01 | -0.11 | 0.03 | 0.36 | -0.03 | 0.17 | 0.20 | 0.44 | 0.34 | 0.21 | 0.60 | 0.70 | 1.0 |
| 18 | -0.12 | -0.04 | 0.04 | -0.02 | 0.03 | -0.11 | -0.03 | 0.39 | -0.05 | 0.20 | 0.19 | 0.51 | 0.35 | 0.22 | 0.48 | 0.71 | 0.9 |
| 19 | 0.04 | -0.04 | -0.02 | -0.00 | -0.13 | -0.09 | 0.09 | 0.08 | 0.09 | 0.09 | 0.06 | 0.09 | 0.09 | 0.05 | -0.02 | 0.08 | -0.0 |
| 20 | 0.00 | -0.01 | -0.06 | -0.02 | -0.06 | -0.09 | -0.00 | -0.13 | -0.01 | -0.10 | 0.09 | -0.05 | 0.06 | 0.05 | -0.04 | -0.08 | -0.0 |
| 21 | -0.03 | 0.05 | -0.00 | 0.01 | 0.03 | -0.09 | 0.05 | 0.49 | -0.11 | 0.20 | 0.07 | 0.64 | 0.31 | 0.10 | -0.04 | 0.59 | 0.2 |
| 22 | -0.03 | -0.00 | -0.09 | -0.03 | -0.02 | -0.13 | 0.09 | -0.01 | 0.04 | -0.03 | 0.03 | 0.02 | 0.05 | 0.00 | -0.01 | -0.02 | 0.0 |
| 23 | 0.05 | 0.02 | 0.15 | 0.12 | 0.12 | 0.07 | 0.04 | -0.03 | -0.07 | -0.03 | 0.08 | 0.01 | -0.04 | -0.05 | -0.00 | -0.01 | -0.0 |
| 24 | -0.09 | 0.02 | 0.16 | 0.06 | 0.15 | 0.08 | 0.09 | -0.04 | -0.10 | -0.11 | 0.23 | 0.05 | 0.12 | 0.08 | 0.03 | 0.03 | 0.0 |
| 25 | -0.04 | -0.05 | 0.04 | 0.06 | 0.04 | 0.11 | 0.11 | -0.01 | -0.04 | -0.03 | 0.33 | 0.08 | 0.21 | 0.18 | 0.05 | 0.06 | 0.1 |
| 26 | -0.08 | -0.05 | 0.08 | [illegible] | 0.09 | 0.07 | 0.06 | -0.02 | -0.05 | -0.03 | 0.32 | 0.09 | 0.19 | 0.13 | 0.11 | 0.09 | 0.2 |
| N= | 213 | 212 | 203 | 213 | 210 | 172 | 177 | 177 | 177 | 177 | 194 | 194 | 194 | 194 | 187 | 188 | 18 |
| M= | 130.7 | 105.8 | 105.6 | 99.3 | 72.7 | 71.6 | 37.0 | 85.2 | 134.4 | 217.6 | 44.2 | 98.1 | 156.6 | 254.9 | 46.0 | 96.7 | 155. |
| S= | 14.7 | 13.9 | 14.3 | 15.2 | 10.7 | 24.6 | 13.5 | 43.9 | 37.7 | 80.5 | 16.1 | 66.7 | 49.9 | 76.5 | 17.4 | 65.2 | 46. |

1. Age
2. Wechsler Intelligence Scale for Children
3. Otis Test of Mental Ability
4. Primary Mental Abilities Test
5. Academic Achievement
6. Chopped Speech Test
7. Photic Frontal first component
8. " " second component
9. " " third component
10. " " fourth component
11. Photic Central first component
12. " " second component
13. " " third component
14. " " fourth component
15. Photic Occipital first component
16. " " second component
17. " " third component
18. " " fourth component
19. Somatic Central first component
20. " " second component

CORRELATION MATRIX

Anpendix A

| 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PF4 | PC1 | PC2 | PC3 | PC4 | PO1 | PO2 | PO3 | PO4 | SC1 | SC2 | SC3 | SC4 | AC1 | AC2 | AC3 | AC4 |
| 0.01 | -0.14 | -0.07 | -0.11 | -0.07 | -0.14 | -0.07 | -0.14 | -0.12 | 0.04 | 0.00 | -0.03 | -0.03 | 0.05 | -0.09 | -0.04 | -0.08 |
| 0.04 | -0.02 | 0.06 | 0.02 | -0.02 | -0.00 | 0.05 | -0.06 | -0.04 | -0.04 | -0.01 | 0.05 | -0.00 | 0.02 | 0.02 | -0.05 | -0.05 |
| 0.02 | 0.02 | 0.06 | -0.05 | -0.11 | 0.11 | 0.11 | 0.04 | 0.04 | -0.02 | -0.06 | -0.00 | -0.09 | 0.15 | 0.16 | 0.04 | 0.08 |
| 0.07 | -0.01 | 0.01 | -0.12 | -0.13 | -0.03 | 0.02 | -0.07 | -0.02 | -0.00 | -0.02 | 0.01 | -0.08 | 0.12 | 0.06 | -0.06 | -0.04 |
| 0.01 | 0.03 | 0.08 | -0.03 | -0.09 | 0.04 | 0.08 | 0.01 | 0.03 | -0.13 | -0.06 | 0.03 | -0.02 | 0.12 | 0.15 | 0.04 | 0.09 |
| 0.00 | 0.02 | -0.02 | -0.14 | -0.15 | -0.05 | -0.02 | -0.11 | -0.11 | -0.09 | -0.09 | -0.09 | -0.13 | 0.07 | 0.08 | 0.11 | 0.07 |
| 0.40 | -0.04 | -0.01 | -0.00 | -0.00 | 0.06 | -0.00 | 0.03 | -0.03 | 0.09 | -0.00 | 0.05 | 0.09 | 0.04 | 0.09 | 0.11 | 0.06 |
| 0.69 | 0.04 | 0.77 | 0.35 | 0.13 | 0.10 | 0.75 | 0.36 | 0.39 | 0.08 | -0.13 | 0.49 | -0.01 | -0.03 | -0.04 | -0.01 | -0.02 |
| 0.76 | 0.06 | -0.08 | 0.13 | 0.15 | 0.16 | -0.12 | -0.03 | -0.05 | 0.09 | -0.01 | -0.11 | 0.04 | -0.07 | -0.10 | -0.04 | -0.05 |
| 1.00 | 0.04 | 0.38 | 0.25 | 0.15 | 0.14 | 0.34 | 0.17 | 0.20 | 0.09 | -0.10 | 0.20 | -0.03 | -0.03 | -0.11 | -0.03 | -0.03 |
| 0.04 | 1.00 | 0.30 | 0.47 | 0.43 | 0.22 | 0.12 | 0.20 | 0.19 | 0.06 | 0.09 | 0.07 | 0.03 | 0.08 | 0.23 | 0.33 | 0.32 |
| 0.38 | 0.30 | 1.00 | 0.64 | 0.39 | 0.09 | 0.87 | 0.44 | 0.51 | 0.09 | -0.05 | 0.64 | 0.02 | 0.01 | 0.05 | 0.08 | 0.09 |
| 0.25 | 0.47 | 0.64 | 1.00 | 0.91 | 0.18 | 0.41 | 0.34 | 0.35 | 0.09 | 0.06 | 0.31 | 0.05 | -0.04 | 0.12 | 0.21 | 0.19 |
| 0.15 | 0.43 | 0.39 | 0.91 | 1.00 | 0.14 | 0.15 | 0.21 | 0.22 | 0.05 | 0.05 | 0.10 | 0.00 | -0.05 | 0.08 | 0.18 | 0.13 |
| 0.14 | 0.22 | 0.09 | 0.18 | 0.14 | 1.00 | 0.32 | 0.60 | 0.48 | -0.02 | -0.04 | -0.04 | -0.01 | -0.00 | 0.03 | 0.05 | 0.11 |
| 0.34 | 0.12 | 0.87 | 0.41 | 0.15 | 0.32 | 1.00 | 0.70 | 0.71 | 0.08 | -0.08 | 0.59 | -0.02 | -0.01 | 0.03 | 0.06 | 0.09 |
| 0.17 | 0.20 | 0.44 | 0.34 | 0.21 | 0.60 | 0.70 | 1.00 | 0.91 | -0.00 | -0.04 | 0.29 | 0.04 | -0.00 | 0.09 | 0.15 | 0.20 |
| 0.20 | 0.19 | 0.51 | 0.35 | 0.22 | 0.48 | 0.71 | 0.91 | 1.00 | -0.02 | -0.07 | 0.32 | -0.01 | -0.00 | 0.05 | 0.09 | 0.14 |
| 0.09 | 0.06 | 0.09 | 0.09 | 0.05 | -0.02 | 0.08 | -0.00 | -0.02 | 1.00 | 0.69 | 0.47 | 0.38 | 0.06 | 0.04 | 0.04 | 0.05 |
| 0.10 | 0.09 | -0.05 | 0.06 | 0.05 | -0.04 | -0.08 | -0.04 | -0.07 | 0.69 | 1.00 | 0.54 | 0.61 | 0.05 | 0.10 | 0.12 | 0.11 |
| 0.20 | 0.07 | 0.64 | 0.31 | 0.10 | -0.04 | 0.59 | 0.29 | 0.32 | 0.47 | 0.54 | 1.00 | 0.57 | 0.04 | 0.11 | 0.16 | 0.15 |
| 0.03 | 0.03 | 0.02 | 0.05 | 0.00 | -0.01 | -0.02 | 0.04 | -0.01 | 0.38 | 0.61 | 0.57 | 1.00 | 0.05 | 0.14 | 0.19 | 0.19 |
| 0.03 | 0.08 | 0.01 | -0.04 | -0.05 | -0.00 | -0.01 | -0.00 | -0.00 | 0.06 | 0.05 | 0.04 | 0.05 | 1.00 | 0.55 | 0.46 | 0.44 |
| 0.11 | 0.23 | 0.05 | 0.12 | 0.08 | 0.03 | 0.03 | 0.09 | 0.05 | 0.04 | 0.10 | 0.11 | 0.14 | 0.55 | 1.00 | 0.80 | 0.70 |
| 0.03 | 0.33 | 0.08 | 0.21 | 0.18 | 0.05 | 0.06 | 0.15 | 0.09 | 0.04 | 0.12 | 0.16 | 0.19 | 0.46 | 0.80 | 1.00 | 0.88 |
| 0.03 | 0.32 | 0.09 | 0.19 | 0.13 | 0.11 | 0.09 | 0.20 | 0.14 | 0.05 | 0.11 | 0.15 | 0.19 | 0.44 | 0.70 | 0.88 | 1.00 |
| 177 | 194 | 194 | 194 | 194 | 187 | 188 | 188 | 188 | 192 | 192 | 192 | 192 | 181 | 181 | 181 | 181 |
| 17.6 | 44.2 | 98.1 | 156.6 | 254.9 | 46.0 | 96.7 | 155.3 | 245.1 | 35.7 | 78.0 | 135.9 | 228.4 | 31.8 | 70.5 | 124.9 | 225.4 |
| 80.5 | 16.1 | 66.7 | 49.9 | 76.5 | 17.4 | 65.2 | 46.3 | 71.7 | 14.3 | 22.3 | 52.2 | 67.0 | 8.9 | 18.0 | 37.7 | 79.3 |

11. Photic Central first component
12. " " second component
~~13. " " third component~~
14. " " fourth component
15. Photic Occipital first component
~~16. " " second component~~
17. " " third component
18. " " fourth component
~~19. Somatic Central first component~~
20. " " second component
21. Somatic Central third component
22. " " fourth component
~~23. Auditory Central first component~~
24. " " second component
25. " " third component
26. " " fourth component