MEASUREMENT OF THE IMPULSE RESPONSE OF THE HUMAN VISUAL SYSTEM USING CORRELATION TECHNIQUES

THESIS

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Presented to the Faculty of the School of Engineering

of the Air Force Institute of Technology

Air University

In Partial Fulfilment of the

Requirements for the Degree of

Master of Science in Electrical Engineering

Edward A. Colley, B.S.

Captain, USAF

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Preface

The purpose of this research effort was to verify that I could apply random signal testing techniques that are widely used for linear systems to the human visual system. While the impulse response curves that I calculated were apparently very good, the verification of this data using matched filter theory was not as successful. More work on this technique might prove very useful.

I am most indebted to two individuals for their contributions to this work. Col Charles P. Hatsell originated the idea of applying these ideas from linear system theory to an organic system. He provided me with very valuable assistance in starting this work. My faculty advisor, Matthew Kabrisky, PhD, allowed me the latitude to pursue those avenues that interested men most. Dr Kabrisky helped me technically, professionally, and personally. I will always remember him as a friend.

Without the support of the many professionals who work at the Armstrong Aerospace Medical Research Laboratory this work would not have been possible. To all of those who helped me I offer my sincere appreciation.

Edward A. Colley

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Abstract

This research applies random signal testing techniques to the human visual system. A binary maximal length sequence was used to modulate a fluorescent light bank by about 15%. With this pseudo-random noise as a visual input, subjects were monitored with an electroencephalograph. The cross-correlation between the pseudo-random input and the EEG output yields an estimate of the subject's visual system impulse response. An attempt was made to verify the impulse response using matched filter theory.

MEASUREMENT OF THE IMPULSE RESPONSE OF THE HUMAN VISUAL SYSTEM USING CORRELATION TECHNIQUES

I. Introduction

This thesis research attempts to characterize the human visual system using classical linear system identification techniques. The particular characterization sought is the system impulse response obtained by random signal testing, a correlation technique. The verification assumes that the impulse response derived in the first part of the experiment for each subject is correct. Using a time reversed (or reflected) version of the impulse response as a visual input signal, the output of the assumed linear visual system is expected to be the autocorrelation function of the system impulse response. The similarities between the theoretical autocorrelation function and the system output from the verification procedure are compared qualitatively.

Background

The Armstrong Aerospace Medical Research Laboratories (AAMRL) sponsored this research. The possibility of using classical linear system characterization techniques, specifically correlation techniques, to characterize the human visual system was first proposed by the past commander of AAMRL, Col Charles P. Hatsell.

There exist at least two potential Air Force applications for this research. One possible application could improve the modulation scheme used on enunciator lights in the cockpit. Knowledge of the impulse response of any system allows the most efficient transfer of energy (or perhaps information) through that system. Another application could allow reliable detection of the state of consciousness (or unconsciousness) of a pilot in near real time during flight by monitoring his impulse response.

Problem Statement

This research experimentally derived the system impulse response of the human visual system for each of five test subjects. This result was used to create a matched visual input signal for each subject. For this experiment, the definition of the human visual system was expanded to include the eye, the optic nerve, the brain, and the electroencephalograph (instrumentation used to measure electrical potential differences in the brain). The electroencephalogram (EEG) was defined to be the output signal. The input signal was put into the system by modulating a simple pair of white fluorescent light bulbs.

Constraints

The thought of characterizing the human visual system as a linear system at first seems absurd. The visual system is non-linear. With a dynamic range of up to 120 dB, as is the case with a healthy eye, few engineers would expect the system to be linear throughout this range as well.

Why would anyone propose to model such a system as linear? No realizable system, of course, is ever truly linear over all possible inputs. Linearization is an assumption made so that a multitude of generalized tools can be applied to the analysis of the system; no such generalized tools exist for the analyses of non-linear systems. But, if deviations from the idealized linear assumption are small, the analysis using classical linear system theory will be very close to the actual system behavior. In this experiment all of the visual inputs were a small fraction of the ambient, or D.C. light level. This constraint helped to ensure that the linear system assumption was reasonably valid and perhaps useful.

Correlation Technique

The experimental determination of the impulse response of the human visual system employed a correlation technique based on using a maximal length sequence as an input signal. This review establishes the requirements and constraints on the input signal and reviews the derivation of the impulse response from the cross correlation of the input function and the system output function.

The cross-correlation function, $R_{xy}(\tau)$, between any two functions, $x(t)$ and $y(t)$, is given by the equation

$$R_{xy}(\tau) \equiv \lim_{T \to \infty} \left[1/T \int_{-T/2}^{T/2} x(t) \cdot y(t+\tau)\, dt \right] \tag{1}$$

where τ is the time shift between the two functions. The cross-correlation function can be thought of as the degree of similarity between the two functions as one is offset from the other in time. The autocorrelation function, R_{xx} is the same as the correlation function except the two functions, $x(t)$ and $y(t)$, are identical for all values of t. This yields a function that gives an indication of the similarity between a particular function and itself offset by a time difference τ.

System Identification

Several early investigators developed the basis for correlation techniques applied to the estimation of the impulse responses of linear time invariant systems. One of the earliest papers that dealt with this technique, by Morris Levin, applied statistical estimation theory to the problem of the optimization of the input test signal. The most significant result derived by Levin was that the optimum test signal would have an autocorrelation function that was impulsive (1:50-55). The best example of a function with an impulsive autocorrelation function is white noise (defined to have an autocorrelation function that is a single impulse at the point of zero time delay, $\delta(\tau)$, and zero elsewhere (2:229-230)).

One of the earliest textbooks on system identification to include a complete treatment of the correlation technique is by W. D. T. Davies. In the introduction to the second chapter Davies envisioned the characterization of an industrial machine or process:

> In general the system under investigation will be in operation 24 hours a day, and it would usually be prohibitively expensive, both in manpower and in lost production to consider taking it off line in order to get even a first estimate of its characteristics. Thus the complete identification needs to be carried out on-line, that is without removing the system from the environment in which it was designed to work. A further restriction necessary if the identification procedure requires the introduction of a disturbance signal at the input, is that this disturbance must be applied together with the normal operating signal, and its amplitude must be kept small enough to ensure that the system is not disturbed too far from its (presumably) optimum operating condition. (3:25)

While my research does not deal with an industrial machine or process, it is certainly clear that the human visual system cannot be "taken off line." Davies goes on to suggest if a random signal is applied to the input of a linear time invariant system, an estimate of the impulse response of the system is possible. The estimate of the impulse response is found by computing the cross-correlation between the input test signal and the system output function.

The output of any linear system can be calculated from the convolution integral at any time, t, where $x(t)$ is the system input, $y(t)$ is the output, and $h(t)$ is the system impulse response:

$$y(t) = \int_0^t h(\tau)\cdot x(t-\tau)\, d\tau \tag{2}$$

If the system is real, and therefore causal, the lower limit of the integration can be extended to minus infinity. Further if the impulse response decays to zero at positive infinity the upper limit can also be extended to positive infinity. Therefore the convolution integral (Equation 2) can be rewritten as

$$y(t) = \int_{-\infty}^{\infty} h(\tau)\cdot x(t-\tau)\, d\tau \tag{3}$$

If the arbitrary function in the cross-correlation integral in Equation 1, $y(t)$, is set equal to the output of some linear system, the cross-correlation integral can be rewritten in the form

$$R_{xy}(\tau) = \lim_{T\to\infty} \left[1/T \int_{-T/2}^{T/2} x(t) \int_{-\infty}^{\infty} h(\sigma)\, x(t+\tau-\sigma)\, d\sigma\, dt \right] \qquad (4)$$

Note that the variable of integration, σ, was substituted for τ in the convolution integral so that it is not confused with the time shift variable in the cross-correlation. If the order of integration is changed in the last cross-correlation integral, Equation 4 can be written as

$$R_{xy}(\tau) = \int_{-\infty}^{\infty} h(\sigma) \lim_{T\to\infty} \left[1/T \int_{-T/2}^{T/2} x(t)\, x(t+\tau-\sigma)\, dt \right] d\sigma \qquad (5)$$

Looking back at the defining equation of a cross-correlation (Equation 1) it is easy to see that the autocorrelation of $x(\tau-\sigma)$ is given by

$$R_{xx}(\tau-\sigma) = \lim_{T\to\infty} \left[1/T \int_{-T/2}^{T/2} x(t)\, x(t+\tau-\sigma)\, dt \right] \qquad (6)$$

If the autocorrelation, $R_{xx}(\tau-\sigma)$ (Equation 6), is substituted into the equation for the cross-correlation (Equation 5) the result is

$$R_{xy}(\tau) = \int_{-\infty}^{\infty} h(\sigma) R_{xx}(\tau-\sigma)\, d\sigma \qquad (7)$$

If a function was found such that the autocorrelation of the function, $R_{xx}(\tau-\sigma)$, was an impulse centered on the origin, $\delta(\tau)$, then the cross-correlation given in Equation 7 would be

$$R_{xy}(\tau) = \int_{-\infty}^{\infty} h(\sigma) \delta(\tau)\, d\sigma \qquad (8)$$

Recalling the sifting property of an impulse the integration would reduce to the system impulse response such that the cross-correlation of the system input and the system output would be exactly equal to the system impulse response, $h(\tau)$.

One possible function that meets the requirement that the autocorrelation function be an impulse is white noise. However, because white noise can take on any value it would drive the input of the system beyond the range where the underlying assumption of linearity is valid. Also the experimental procedure to estimate accurately the impulse response using a truly random input signal can be very long. For the cross-correlation to be exactly equal to the impulse response the experiment would have to be done for an infinite time (3:37-38).

The experimental difficulties with using random inputs are easily eliminated by using a pseudo-random noise signal for the system input test signal. Idealized pseudo-random noise has a similar autocorrelation function to that of white noise; its autocorrelation function is a train of repeated impulses. Davies demonstrates that if the impulse response of the system under test decays to zero (or nearly zero) in a time that is less than the time delay between the impulses of the autocorrelation function of the pseudo-random test signal, the correlation techniques are still applicable. In fact if the time delay between all of the autocorrelation impulses is a constant, T, the estimate of the system impulse response is simplified significantly. The cross correlation, and the impulse response, are given by integrating only over the period, T,

$$R_{xy}(\tau) = 1/T \int_0^T x(t) \cdot y(t+\tau)\ dt \tag{9}$$

where the input test signal is x(t), and the system output is y(t) (3:39-43).

In Chapter Three of his textbook, Davies suggests the use of binary maximal length sequences for use as a pseudo-random noise source. This chapter provides sufficient tutorial on maximal length sequences so they can be implemented (3:44-88). A much earlier report from the University of Michigan Research Institute (now called the Environmental Research Institute of Michigan) provides a much firmer theoretical basis, however (4). This report shows, in detail, how the autocorrelation function of a binary maximal length sequence approximates a train of triangle pulses as shown in Figure 1.

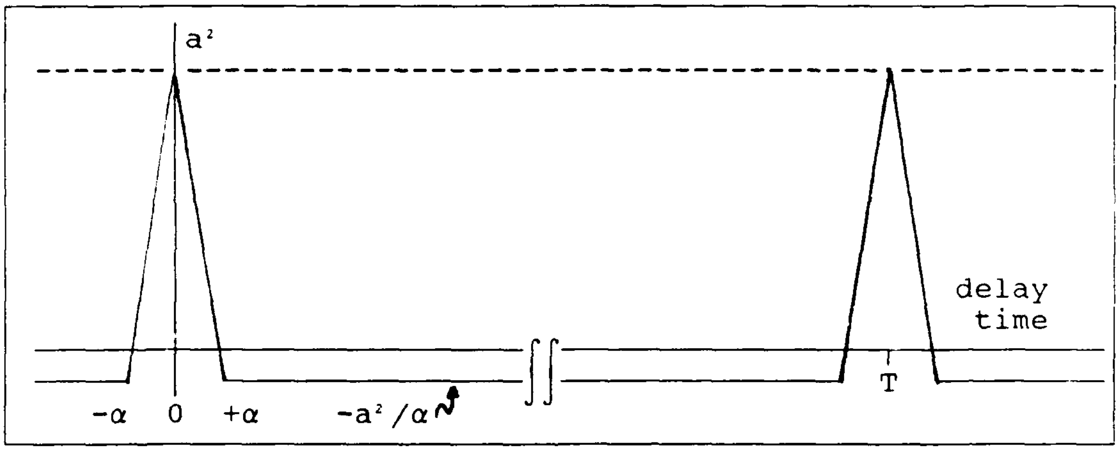

Figure 1. Autocorrelation of a Binary Maximal Length Sequence with binary amplitudes of ±a, pulse duration of α and a total length of T (3:42)

If the duration of the pulse, α, is kept small this pulse train can be modeled as a train of scaled impulses, one of which is centered on the origin. Recall that this was the requirement on the autocorrelation function, $R_{XX}(\tau-\sigma)$ such that the cross-correlation in Equation 8 would reduce to the system impulse response. The remaining "impulses" would of course create replicas of the impulse response curve centered at the location of each impulse if the cross-correlation integration was carried out that far.

The maximal length sequence can be generated by a simple circuit made up of shift registers and modulo-two adders. The generator circuit requires feedback loops; the exact implementation of the feedback, and the necessary primitive polynomials are tabulated (4).

<u>Matched Filter/Matched Signal Response</u>

If the input to a system with an impulse response of $h(t)$ is a time reversed version of the impulse response given by $h(\sigma-t)$, the system output, $y(t)$, can be written as the convolution integral

$$y(t) = \int_{-\infty}^{\infty} h(\tau)\cdot h(\sigma-t+\tau)\, d\tau \qquad (10)$$

The convolution integral above can be shown to be exactly equal to the auto-correlation of the impulse response, $R_{hh}(\sigma-t)$. If the value of σ is chosen large enough so the impulse response has decayed to zero for all values of time greater than σ, then it is possible to apply an exact time reversed version of the impulse response into a causal system. Because of the symmetry properties of the autocorrelation function, $R_{hh}(\sigma - t)$ is just the normal autocorrelation function shifted such that it is centered on $+\sigma$. This value of σ is also the time required to feed in the entire matched signal, $h(\sigma - t)$, into the matched filter.

It can also be shown that the matched signal is the most efficient signal for passing energy through the filter characterized by the impulse response, $h(t)$. However, this fact is not used directly in this research effort.

Resource Requirements

All the resources required for this research were provided by AAMRL. The hardware requirements included all of the required medical equipment for gathering the EEG data, the light bank and its driver, and computer resources. AAMRL also provided technicians and all of the test subjects.

II. Experimental Set Up and Procedure

Experimental Procedure

Each subject was connected to the electroencephlograph by a qualified medical technician. The subject was then asked to fix his/her attention on a fluorescent light bulb that was modulated by a 16,383 bit maximal length sequence between two intensities at a rate of 500 bits per second. This sequence was repeated three times. The output EEG was sampled at a rate of 500 samples per second and stored in computer memory along with the input maximal length sequence. An estimate of the subject's visual system impulse response was computed from these data using a numeric implementation of the cross-correlation integral in Equation 9 of Chapter 1. The computed impulse response was then reversed (or reflected) in time. The time reversed impulse response was then applied as a visual input and the output EEG was recorded again. This output is compared to the computed autocorrelation of the estimated impulse response in an attempt to verify the validity of the results.

Input Light Source

An ideal light source for this experiment would be absolutely linear, and have a flat frequency response.

However, the actual light source was not ideal. Figure 2 shows the actual output (as seen by a high quality photo diode) of the light source when a 20 cycle per second square wave was used as a modulation source. These traces are inverted; i.e. down represents a more intense light level.

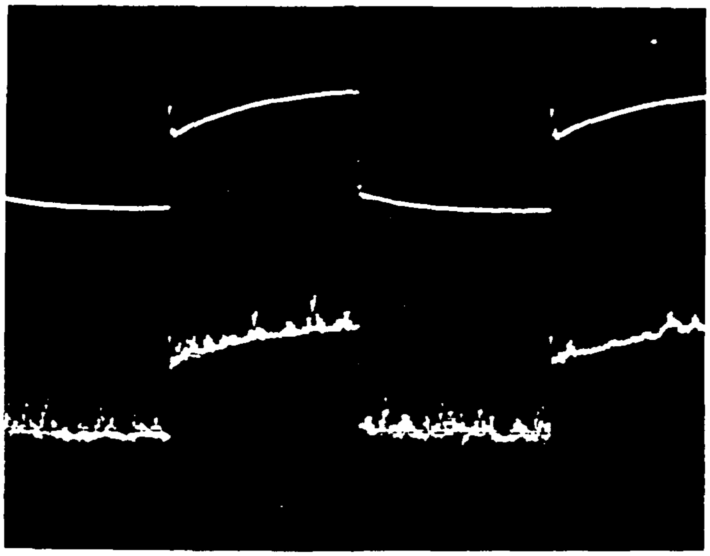

Figure 2. Sample Light Bank Output with Square Wave Input Signal

The peak-to-peak light level is approximately 15% of the maximum light intensity. All the experiments were run using this 15% modulation. The picture shows two different waveforms because the output was not uniform across the bulbs; the two different waveforms are samples of the output at the two ends of one bulb.

The high frequency noise evident in the lower waveform died down as the bulb "warmed up," however it never went away entirely. This high frequency noise should not alter the experimental results in any way because it is at too high a frequency to be discernible to the human visual system, and it is uncorrelated to the input signal.

The general shape of the waveform would, ideally, be a square wave. The actual shape is the result of non-uniform phase delays, non-uniform amplitude response for different frequencies, and non-linearities.

The non-uniform phase delays and amplitude response are combined with the response of the system under test in this experiment. Their effect could be reduced or eliminated by sampling the actual light source as seen by the subject, however this approach would cause additional problems. Part of the effect of the light bulbs and drivers on the input waveform could be modeled as the effect of a linear low-pass filter. The effect of a lowpass filter on the autocorrelation function is too smear, or broaden, the function. This smearing of the autocorrelation function could be enough to violate the basic assumption that the autocorrelation of the input function is a reasonable approximation of an impulse.

The non-linearities in the light bulbs and driver were a worse problem because their contribution detracts from the underlying assumption that the system under test is a linear system. The theory developed in Chapter 1 does not allow an estimate of the effect of any non-linearities in the system under test or the test equipment. Because the deviations from a linear system model are small, it is postulated that the effect on the output will also be small.

Figure 3 shows two typical samples of the light bank output when it is modulated by the maximal length sequence. The shortest time in this picture between any two transitions (low-to-high or high-to-low) is 2 msec.

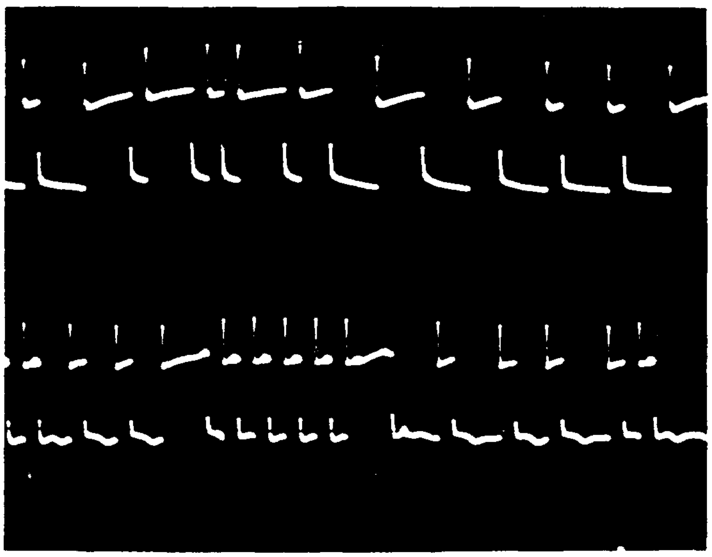

Figure 3. Typical Light Bank Output with Maximal Length Sequence Input Signal

Grass Amplifiers

The output EEG signal was taken from a Grass brand amplifier. This amplifier was set to have a high-pass cuton frequency of 1 Hz and a low-pass cut-off frequency of 100 Hz. The 60 Hz notch filter was not used. Other band-pass frequencies could be selected, however, if the pass-band was restricted further one would expect the ultimate output impulse response to be affected more by the amplifier than the human visual system. The upper setting of 100 Hz was selected, in part, to ensure that there would be very little energy beyond 250 Hz that would be aliased into the output by the 500 samples per second. (Recall the Nyquist Sampling Theorem) The 60 Hz notch filter was not used because any stray signals that are picked up should never correlate with the signal used to modulate the light bank and therefore would not contribute to the resulting impulse response.

The selections made for the EEG amplifier settings should allow an assumption that in the frequency band that is passed by the human visual system the amplifier response is reasonably flat so the derived impulse response is influenced most significantly by the organic human visual system.

Scalp Electrodes

Three electrodes were used on every subject. One electrode was placed on the centerline of the head, over the visual cortex on the back of the head (referred to as OZ). Another electrode was placed behind each ear. The impedance was measured before the start of each experiment to ensure that it was below 5,000 ohms between the center electrode and the electrodes behind each ear. The scalp potential between the center electrode and one of the electrodes behind the ears (whichever had the lowest impedance) was used as the input signal to the Grass amplifier. The electrode behind the other ear was connected to ground.

The impedance measurements were not recorded as they are a function of time. However, it was noted that the results "seemed" to have a better signal to noise ratio when the starting impedance was low.

The electrodes were connected to a terminal box by a thin unshielded wire. The terminal box was connected to the Grass amplifier by a shielded cable.

Ambient Conditions

The subjects sat in a small booth that had no light source except the light from the light bank that was modulated during the experiment and that light which came from the booth's open door. The light bank was never turned off between data runs so the subjects were reasonably well adjusted to the light levels that were used during data collection. The subject's eyes were about 18 inches from the light bulbs. They were asked to fix their attention directly on one spot on either of the two bulbs.

III. Experimental Results

The complete experiment was run on five different subjects. Each complete experiment consisted of three parts:

1) Each subject watched the maximal length sequence of 16,383 bits which was repeated three times without a break for a total of 49,149 bits, or samples. Because each brightness level was held for 1/500 sec, the subject watched the lights for about 1 1/2 minutes. The subjects were given a short break between each data collection run. This was repeated about five times for each subject. For each run of 1 1/2 minutes the cross correlation between the maximal length sequence and the output EEG data was calculated for a shift of up to 500 samples (or one second of data). The average of the impulse response calculated for five trials was calculated.

2) Another sequence of brightness levels was then constructed by reversing the averaged impulse response and appending 500 zeros. This matched signal sequence was normalized to ensure that the light intensity levels were similar to those that the subject saw when he/she watched the maximal length sequence. This sequence was reproduced 100 times for a total of 100,000 samples. The subject watched the light bank as it was modulated for 3 1/3 minutes

by these matched signals. The output EEG signal was separated into 2 second intervals; these intervals were averaged together. This output was expected to resemble the autocorrelation of the impulse response. This was repeated about three times for each subject.

3) To ensure the results derived in part one of this experiment were reasonable another estimate of the impulse response was sought. The subject watched 100 small "impulses" of light, each lasting about 10 msec, repeated at a rate of one per second. For most subjects this test was repeated two or three times. The average response to these impulses is another estimate of the impulse response.

Subject #5

Of the five subjects tested the results from the final subject seemed best. These results are presented first.

Figure 4 shows a typical result for a single trial on the fifth subject. This is the estimate of the impulse response of the subject's visual system. The horizontal axis on every graph in this report is labeled in units of "samples" or "number of sample shifts." Because the data were always presented and sampled at a rate of 500 samples per second, this axis can be converted to seconds by multiplying by 1/500 or .002 seconds per sample. Therefore this graph presents one second worth of data. The units on the vertical axis, on this graph, and every other graph in this report, are not calibrated and therefore have been

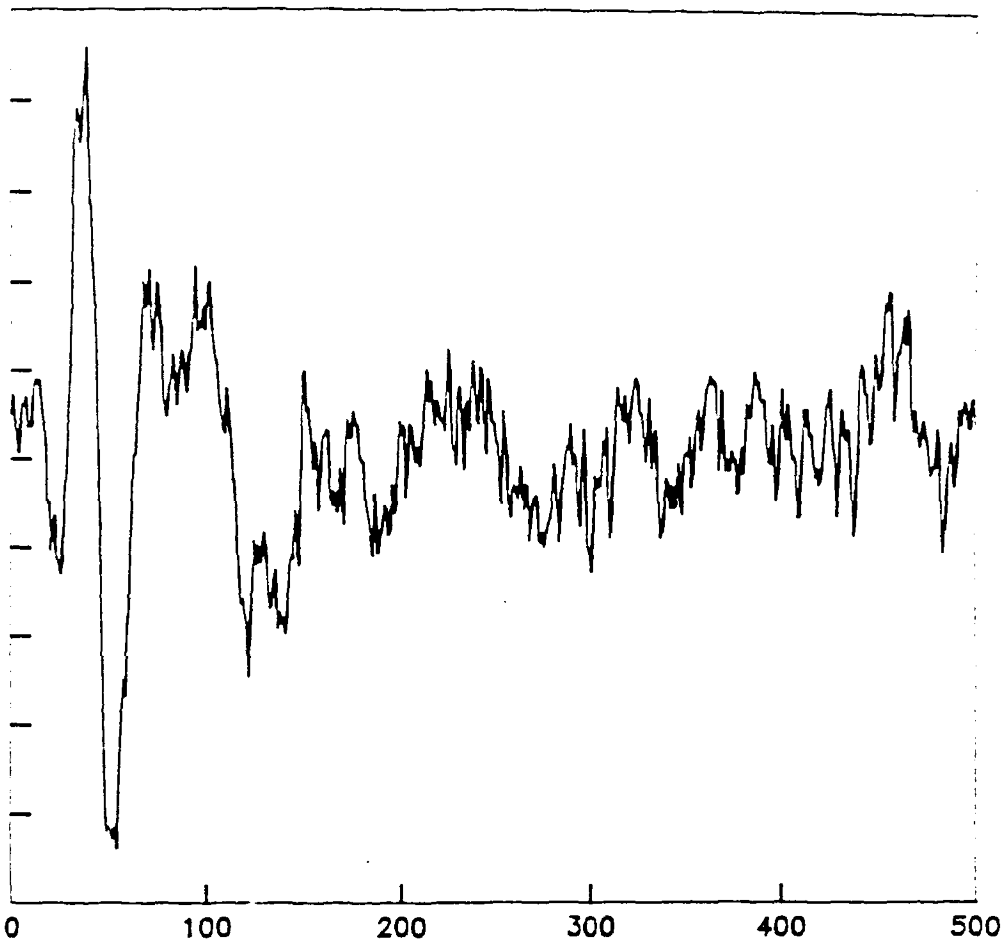

Figure 4. Typical Calculated Impulse Response for Single Trial (Subject #5)

omitted. The scale of this axis is not the same for different plots.

The results of three other trials on the same subject are superimposed in Figure 5. While this graph is of little use directly, it demonstrates that the experiment is reasonably repeatable. This allows the assumption, implied in doing any experiment of this type, that the processes or systems under test are reasonably

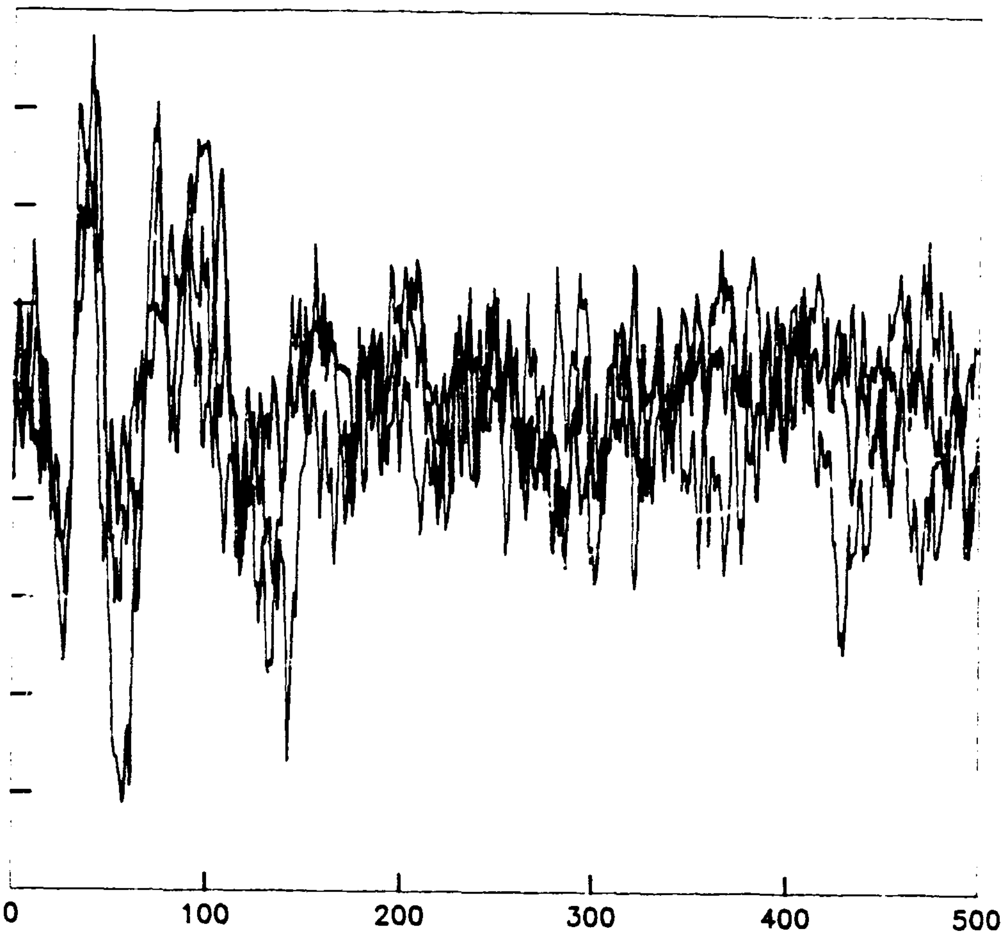

Figure 5. Impulse Response From Three Trials (Subject #5)

stationary. As these trials spanned a period of about 45 minutes, the assumption of a stationary process is validated.

The average of five trials for the fifth subject is graphed in Figure 6. The peak response for this subject was at 82 msec. Very little, if any, response is apparent after 300-400 msec. No response is apparent before about 40 msec.

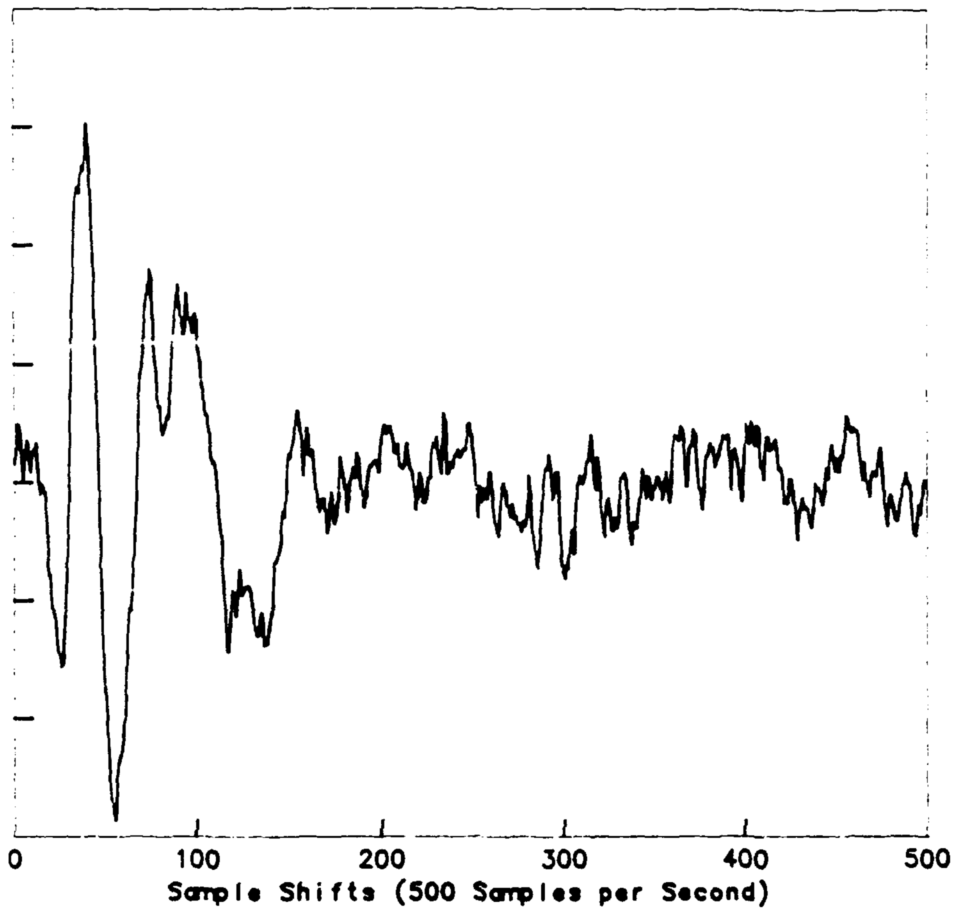

Figure 6. Average Impulse Response (Subject #5)

Figure 7 shows the average response to the matched signal. The horizontal axis on this graph has been adjusted so the center (sample #500) corresponds exactly to the end of the matched signal application and the beginning of the zero padding between matched signals. The local maximum in the center of this graph corresponds very well to the expected position of the autocorrelation peak.

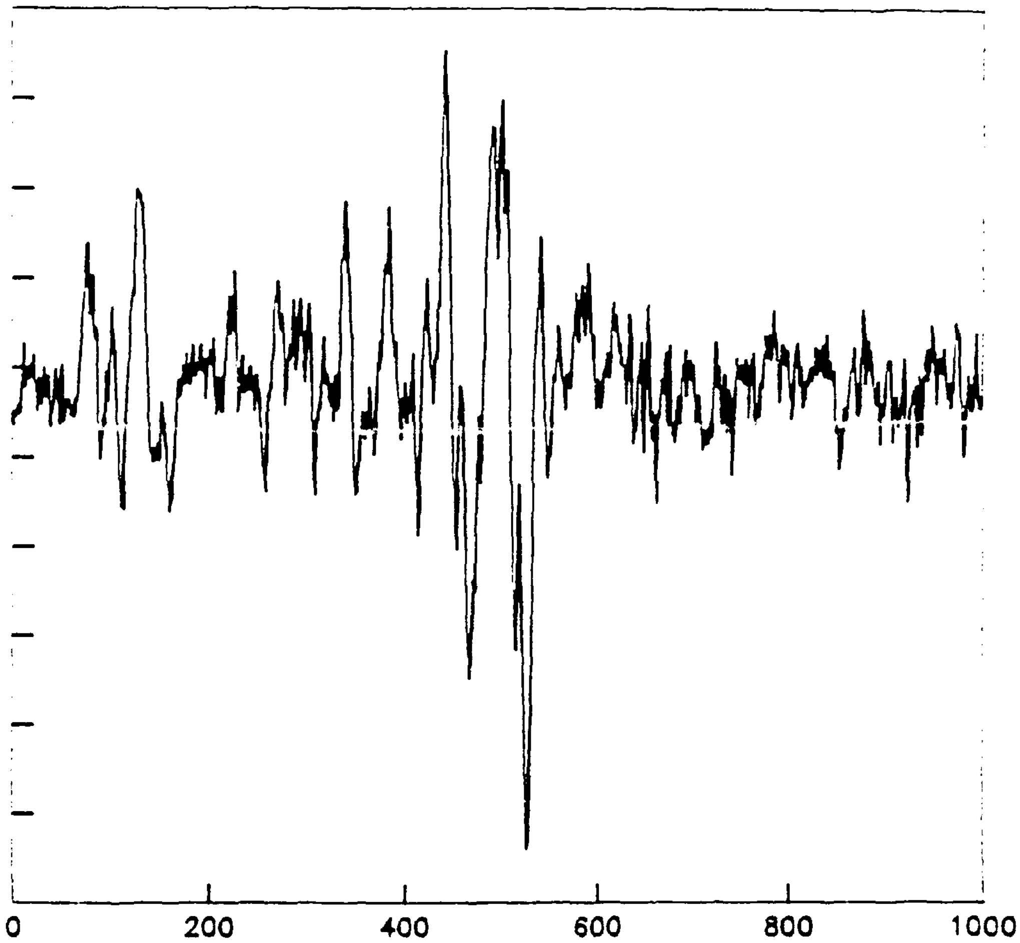

Figure 7. Average Response to Matched Signal (Subject #5)

Figure 8 shows the autocorrelation of the average impulse response. Again the point of zero shift is centered (sample #500) so it can be compared conveniently with the other graphs.

Figure 9 shows, superimposed, the same data as are shown in Figures 7 and 8 with 250 sample points removed on both ends to better show the more interesting data in the middle of the graph If all of the assumptions made in the

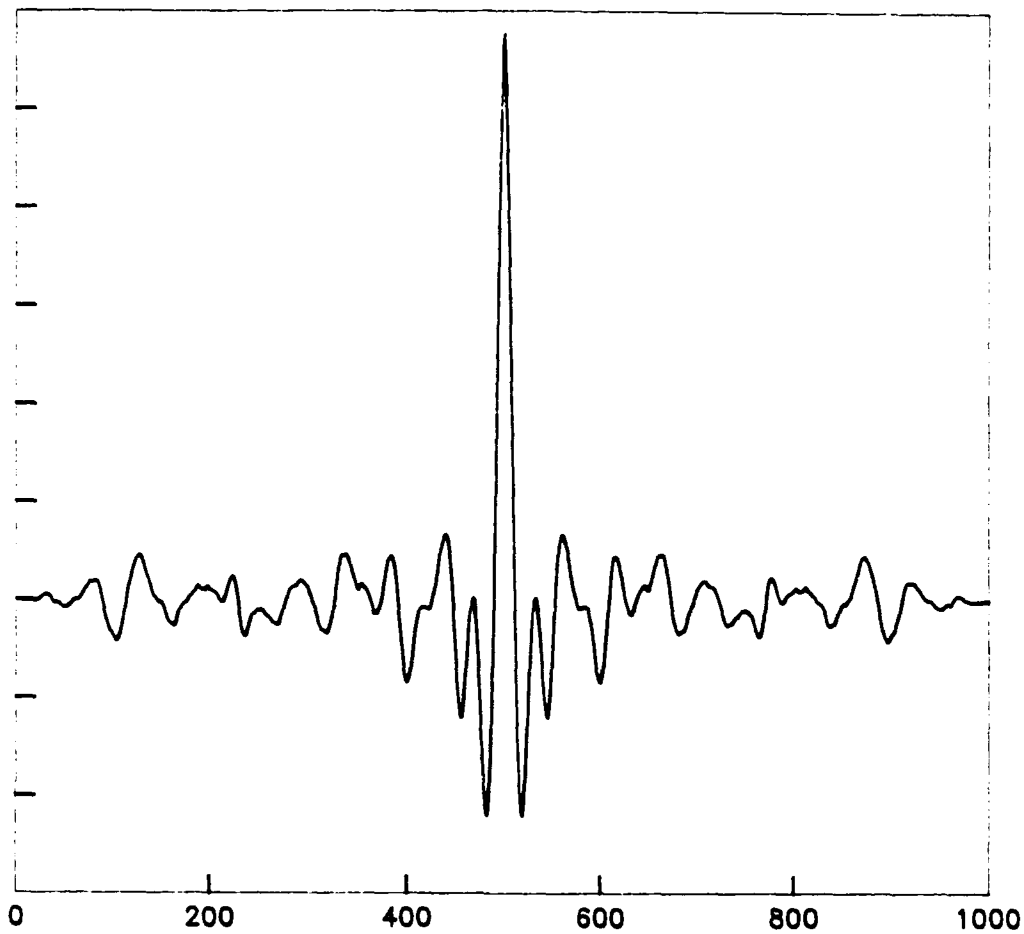

Figure 8. Autocorrelation of Impulse Response (Subject #5)

theoretical derivation were correct, and all of the systems and instrumentation were linear, and there was no noise introduced, these two curves would overlay each other exactly.

One very simple model of the system under test (the human visual system) might be a simple delay line. Reading directly off of the impulse response graph, the peak response for this subject was at 82 msec. The amount of

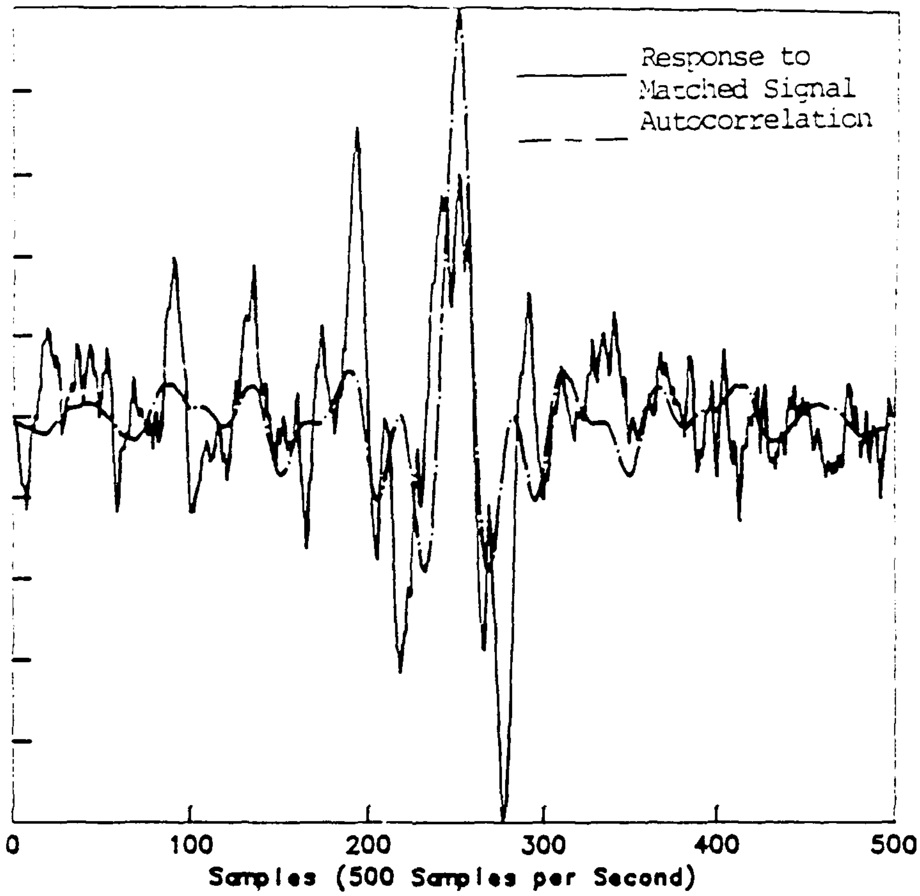

Figure 9. Normalized Matched Signal Response and Autocorrelation of Matched Signal (Subject #5)

delay therefore in the overly simple model would be 82 msec or 41 samples. Figure 10 shows the normalized response to the matched signal, and the matched signal offset by a delay of 41 samples (as it would appear if fed through a delay line). As expected there are many similarities in the two sets of data, however the data in Figure 9 seem to have a better "fit."

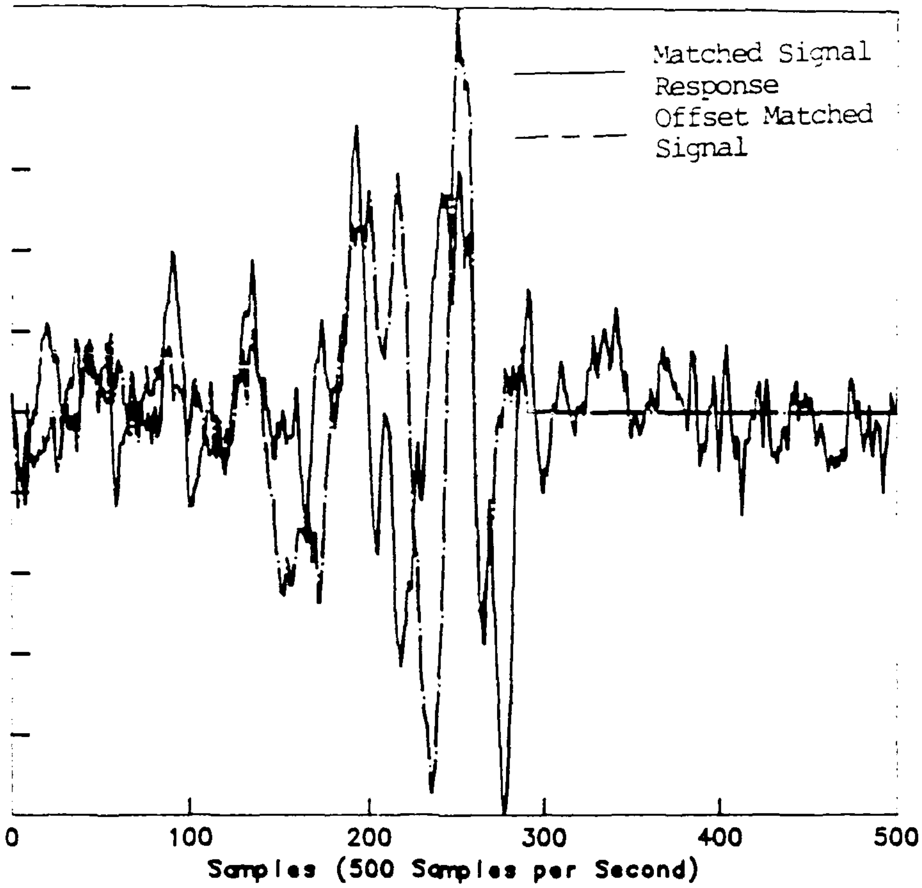

Figure 10. Normalized Matched Signal Response and Matched Signal Offset by 41 Samples (Subject #5)

Figure 11 shows the impulse response derived from random signal testing and that derived from the average response to small pulses. Clearly there are many similarities in the two responses as expected.

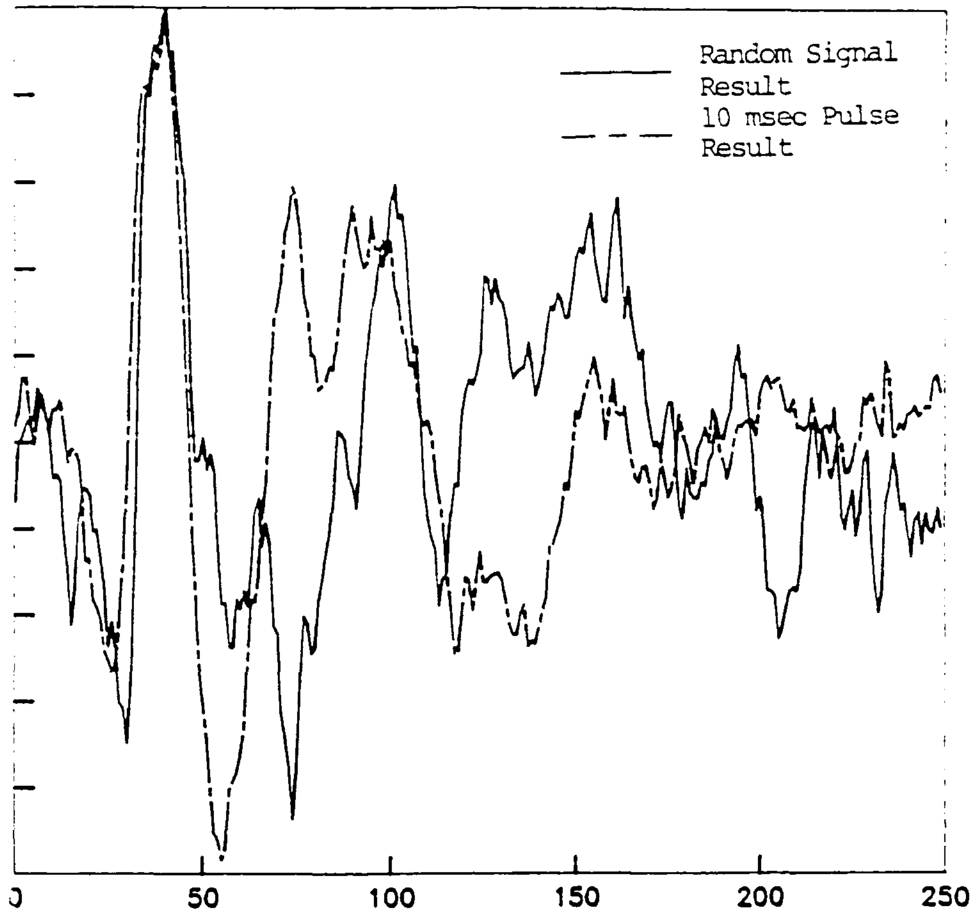

Figure 11. Impulse Response From Random Signal Testing and Average Response to 10 msec Pulses (Subject #5)

Subject #1

The average impulse response for the first test subject is shown in Figure 12. There is an immediately obvious flaw in this particular estimate of the impulse response of the human visual system; there is a very strong response immediately after the impulse is applied. It is certainly

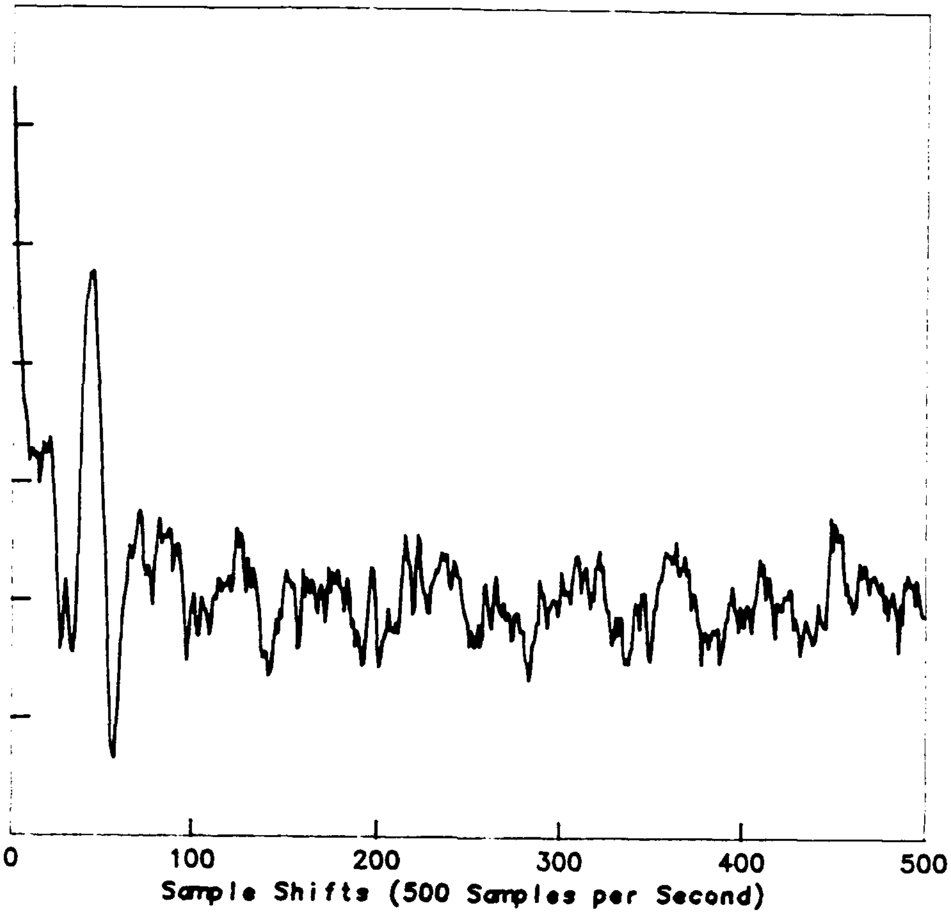

Figure 12. Average Impulse Response (Subject #1)

not possible for the visual system to pass any data along the optic nerve in less than 1 msec.

Another test was done on this subject (and every other subject) that was exactly like the test done to determine the impulse response except the lights were covered with a sheet of black cloth such that the subject could not see the lights. The results of this trial are shown in Figure 13. There is some other mechanism besides the human visual

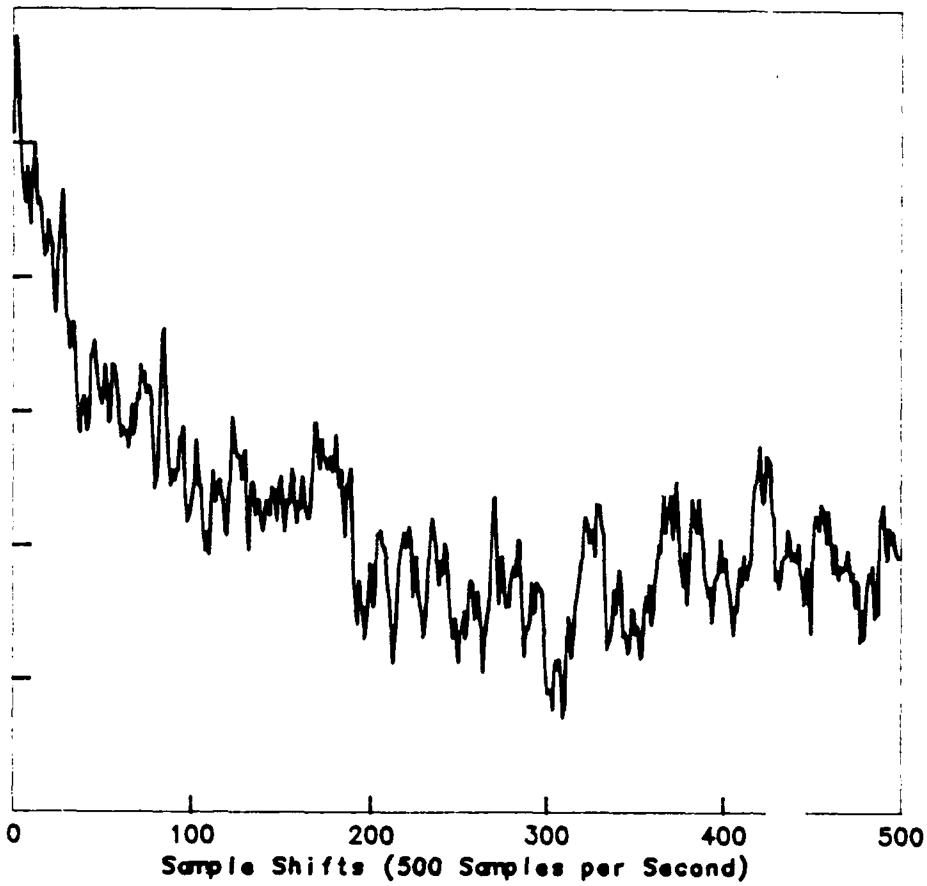

Figure 13. Calculated Impulse Response With Lights Covered (Subject #1)

system that is coupling energy correlated with the maximal length sequence input to the grass amplifier output.

For subsequent subjects an increasing effort was made to keep all of the wires, cables, and equipment that carried the maximal length sequence input data as far away as possible from the wires, cables, and equipment, that carried the EEG data. The eventual success of this effort in eliminating any significant response near zero time for the fifth subject supports the hypothesis that the undesired coupling was from "stray" electro-magnetic fields.

The presence of this undesirable coupling does not negate the value of the experimental results however. The derived impulse response is just the combination of the response from the desired system, and undesired system.

Remaining Subjects

The results of these experiments for the remaining subjects are presented in the appendix. The results are reasonably consistent between subjects, and were always repeatable for each subject.

The average of the "average impulse response" for all five subjects is presented in Figure 14. The peak response on this average was found to be at about 90 msec for this small sample population. This corresponds well with the findings of many other researchers. Often this peak response to an input stimulus is called the P100 point and is expected 100 msec after the introduction of the stimulus.

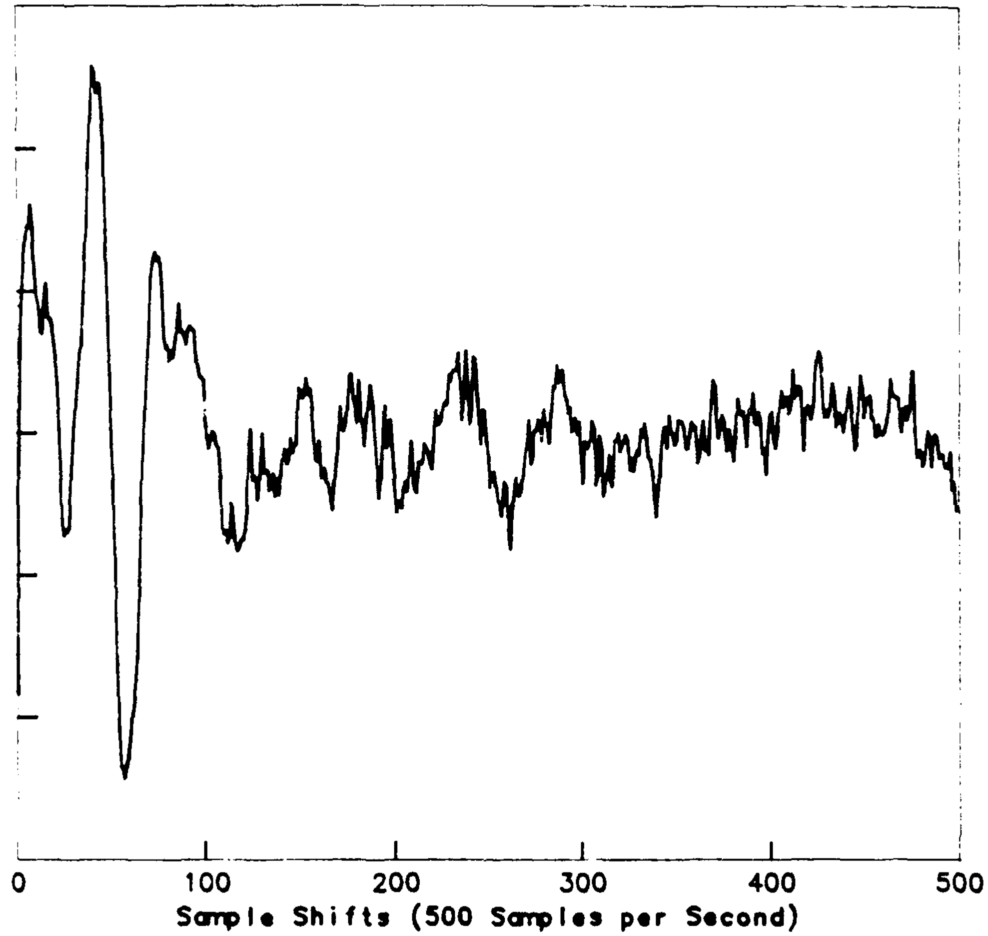

Figure 14. Average Impulse Response for All Subjects

IV. Possible Future Work

This research effort has sucessfully demonstrated the application of random signal testing techniques on the human visual system. The experiment was repeatable, and the signal to noise ratios were certainly positive (expressed in dB) for reasonable sequence lengths.

Testing of other organic systems with this, or similar, techniques might be possible. Could a test be devised to find the impulse response of the auditory channel using random signal testing? Could there be a medical diagnostic use for this type of testing on any human system?

Time constraints did not allow many interesting parts of this specific experiment to be done. Follow-on experimenters could do all or part of the following to make this work more complete.

Because of the problems with undesired coupling mechanisms, any future experiments would almost certainly be enhanced if all of the wires used were shielded. This is especially important for the wires used to connect to the scalp electrodes. It might also be possible to shield the light box itself with an electrically conducting screen.

If the equipment used to transform the computer generated signal into a visual input were made more linear the underlying assumptions in this experiment would be more valid. If the response of this equipment was made essentially flat in the significant frequency band involved it would influence the calculated impulse response less, allowing a better estimate of the impulse response of just the organic human visual system.

Many of the parameters chosen to run this experiment were not tested to find out if they were optimal. Future experimenters could vary the settings on the Grass amplifiers, vary the sample rate, or vary the length of the maximal length sequence. The percent modulation of the input stimulus could also be changed; a smaller signal would reinforce the underlying linear system assumption while a larger signal would tend to give a better signal to noise ratio.

More subjects should be tested... perhaps ten or more... so that the comparison between subjects would be more meaningful. Several of these subjects should be tested on different days to ensure that the response does not change over time. The subjects could be tested under a variety of workloads to determine if there is any significant effect.

Another experiment that could be interesting would be to modulate several small lamps with a variety of waveforms to determine if the matched signal is the most "powerful attention getter." This experiment could test the subject's specific matched signal as well as an average matched signal for many subjects.

Appendix: Complete Data Collection

This appendix includes a complete collection of all of the data collected for all five subjects that participated in this experiment.

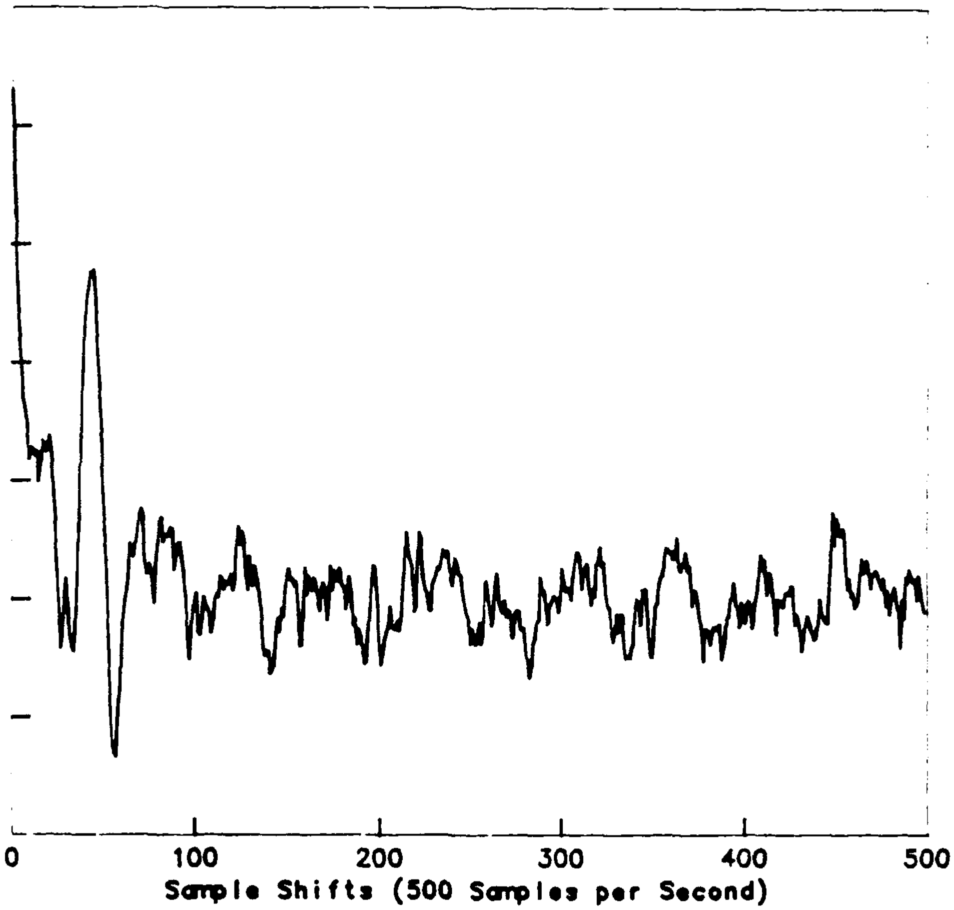

Figure 15. Average Impulse Response (Subject #1)

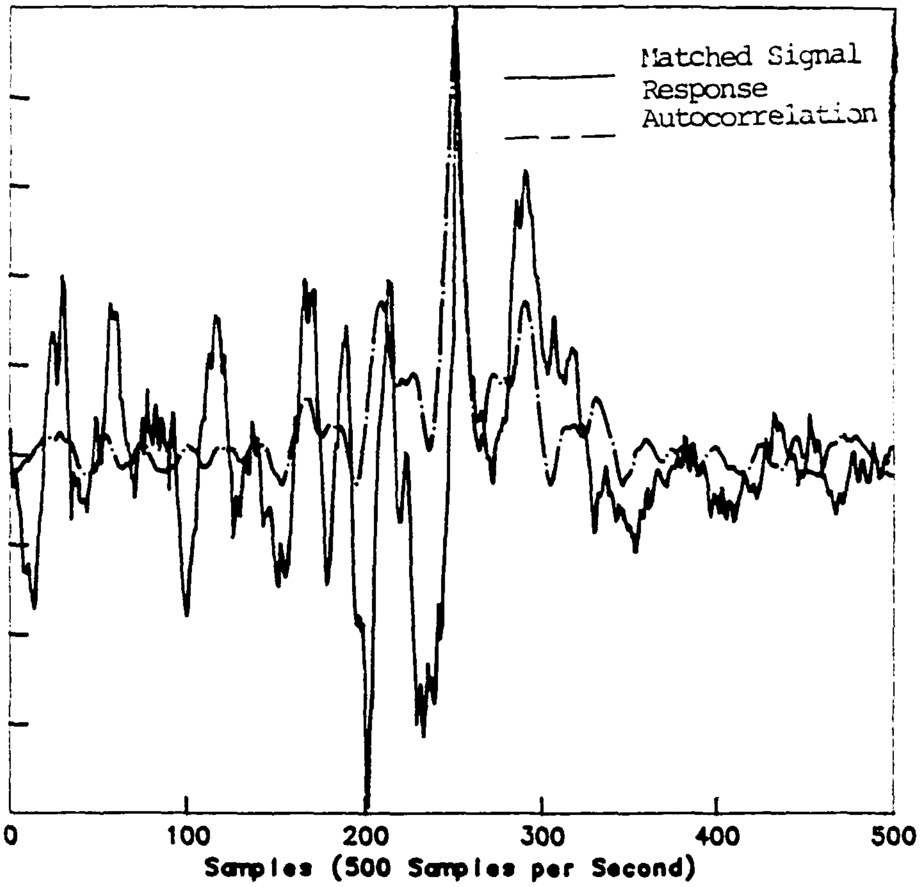

Figure 16. Normalized Matched Signal Response and Autocorrelation of Matched Signal (Subject #1)

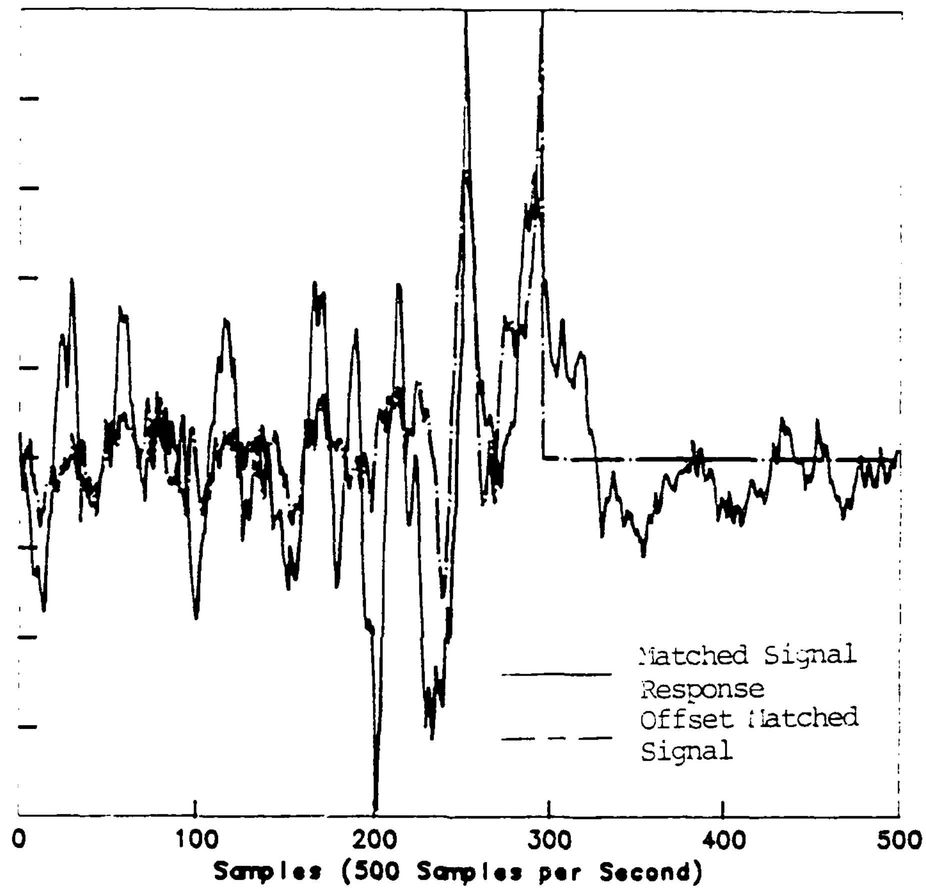

Figure 17. Normalized Matched Signal Response and Matched Signal Offset by 46 Samples (Subject #1)

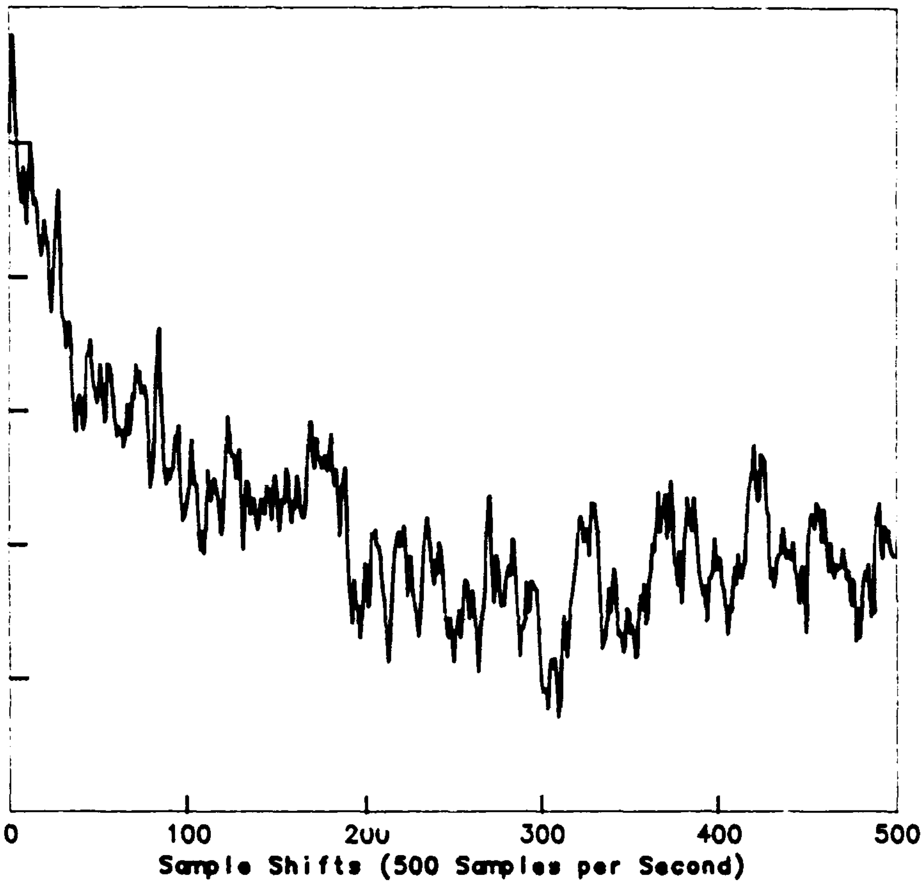

Figure 18. Calculated Impulse Response With Lights Covered (Subject #1)

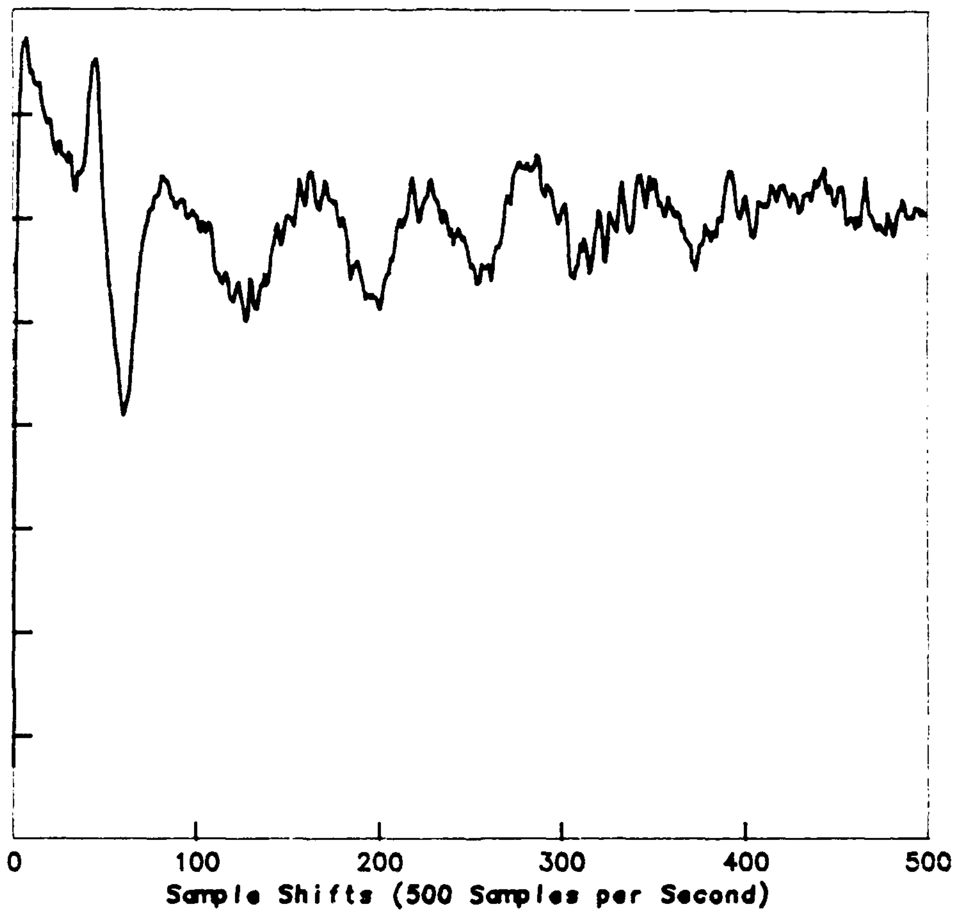

Figure 19. Average Impulse Response (Subject #2)

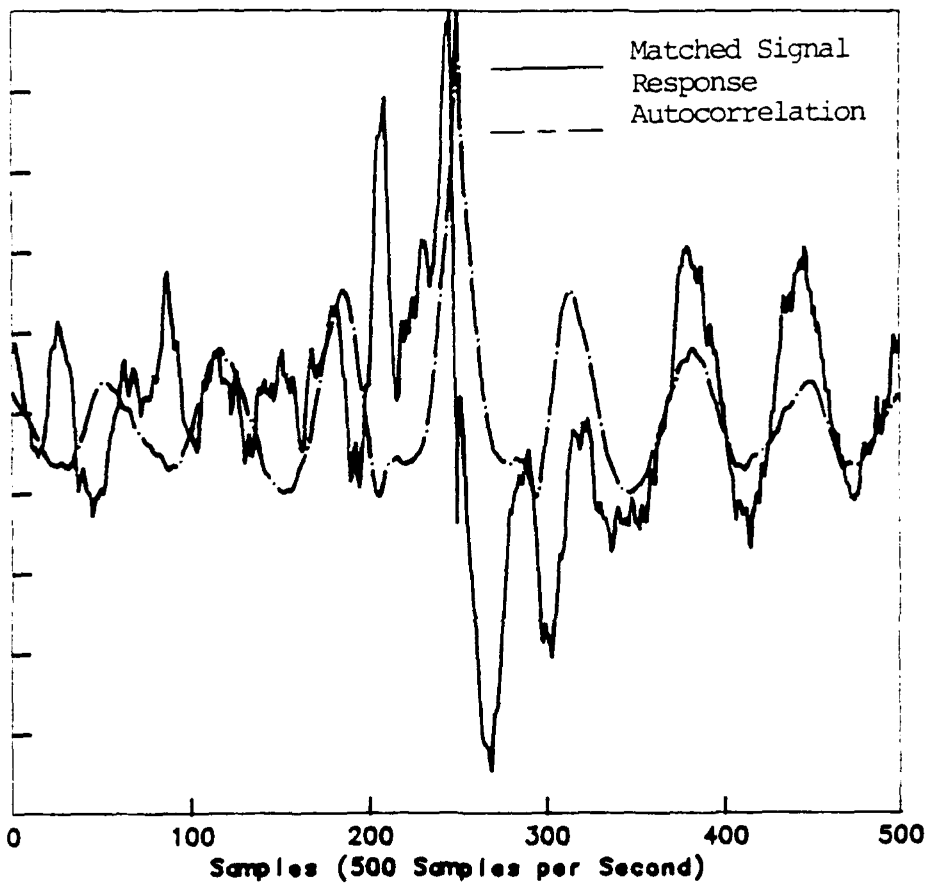

Figure 20. Normalized Matched Signal Response and Autocorrelation of Matched Signal (Subject #2)

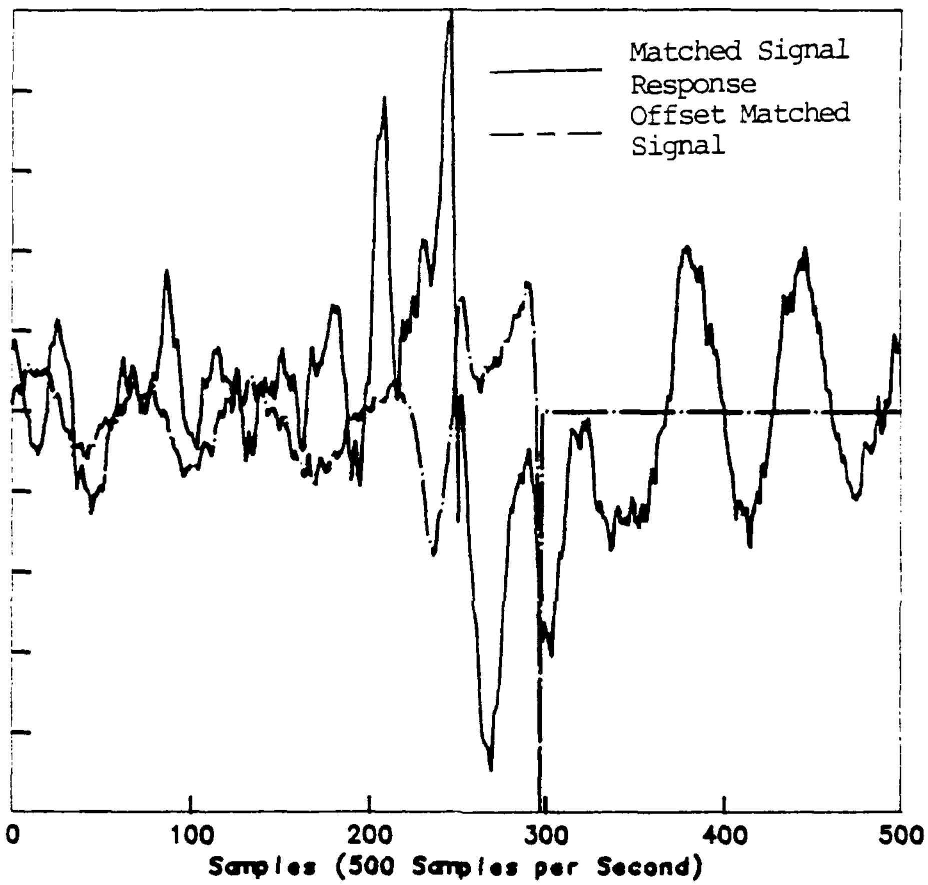

Figure 21. Normalized Matched Signal Response and Matched Signal Offset by 48 Samples (Subject #2)

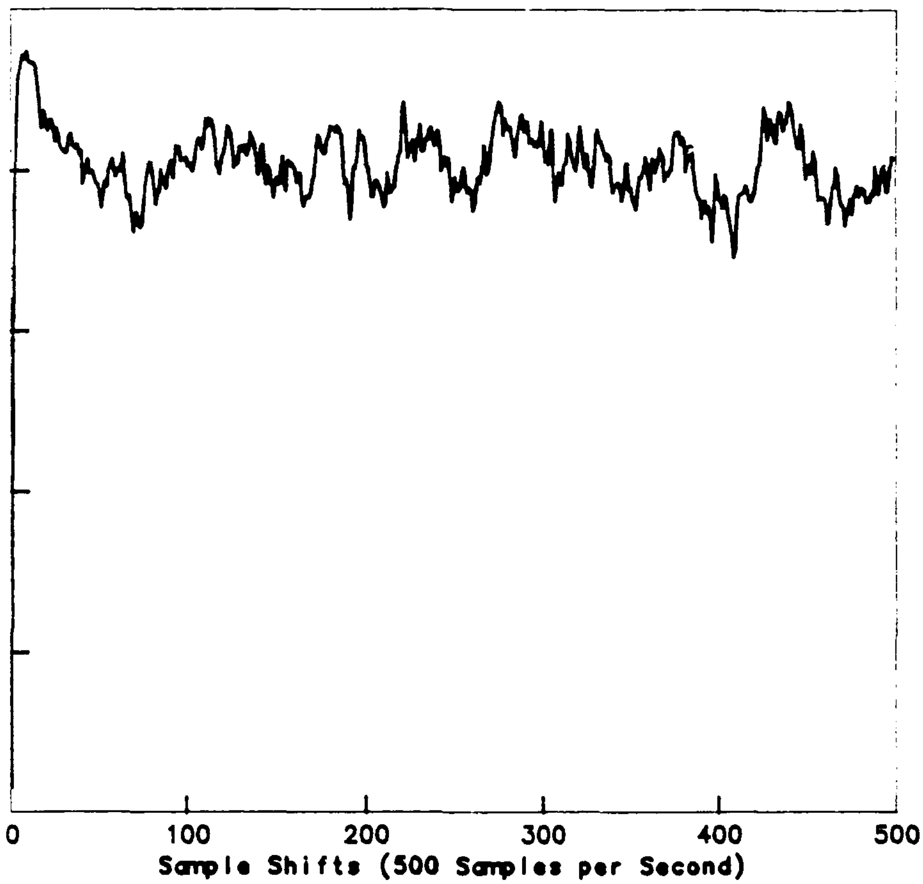

Figure 22. Calculated Impulse Response With Lights Covered (Subject #2)

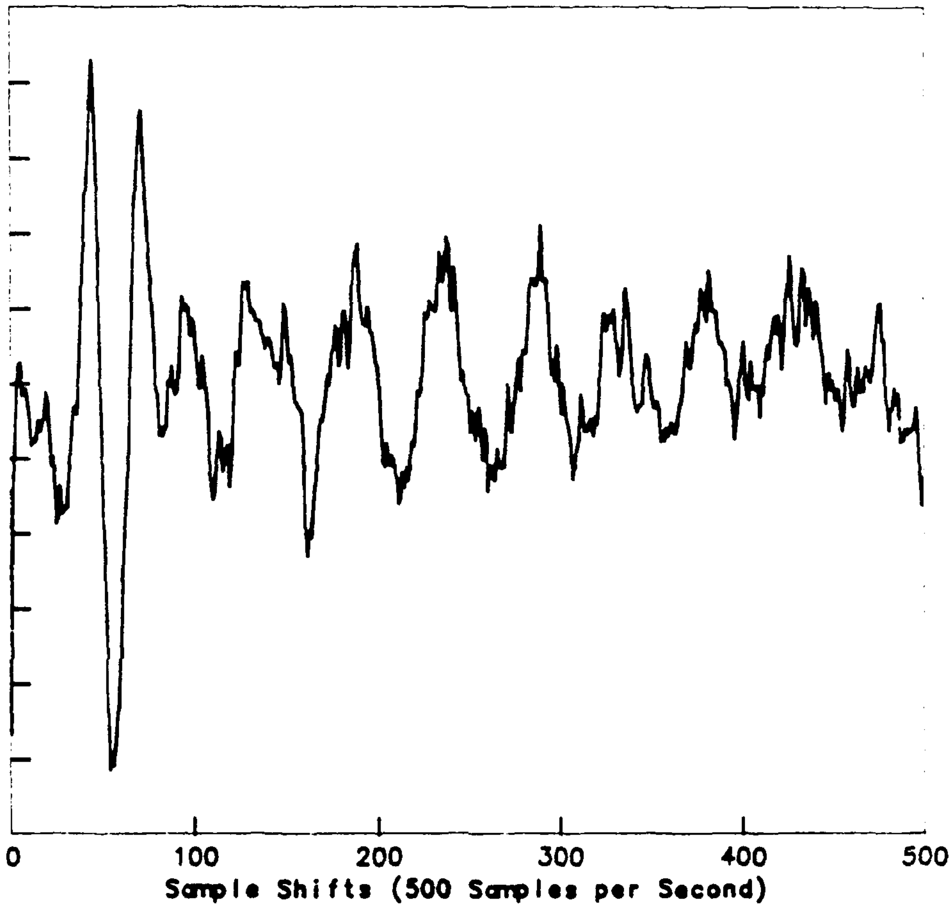

Figure 23. Average Impulse Response (Subject #3)

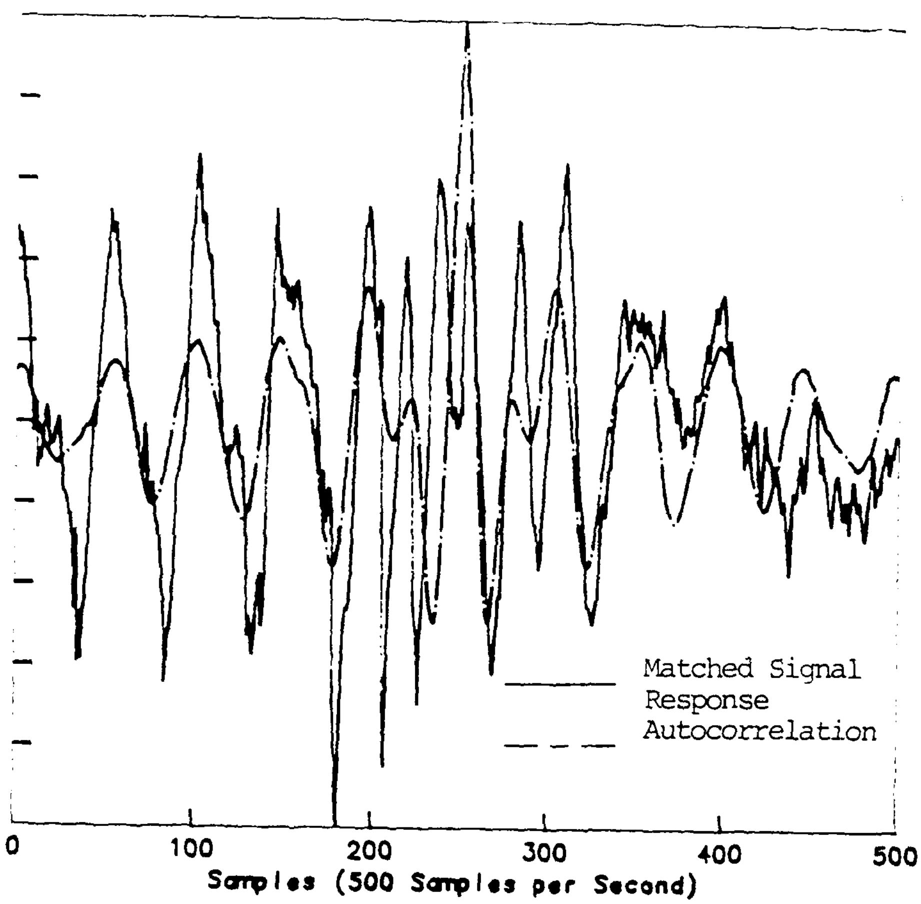

Figure 24. Normalized Matched Signal Response and Autocorrelation of Matched Signal (Subject #3)

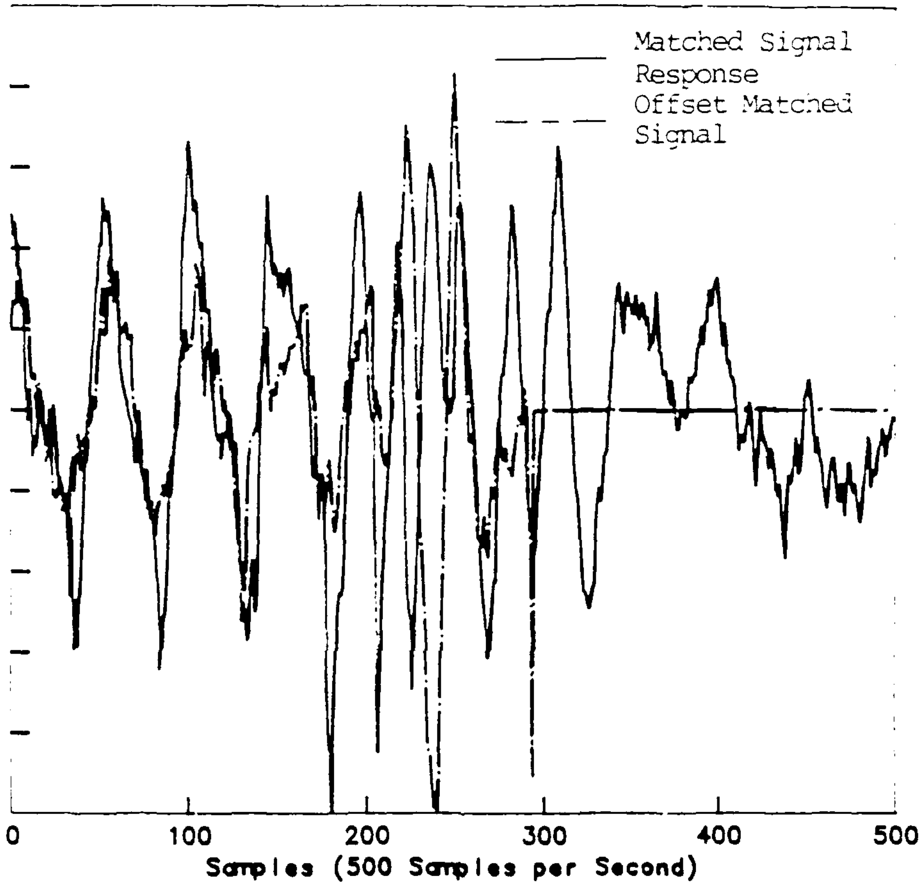

Figure 25. Normalized Matched Signal Response and Matched Signal Offset by 45 Samples (Subject #3)

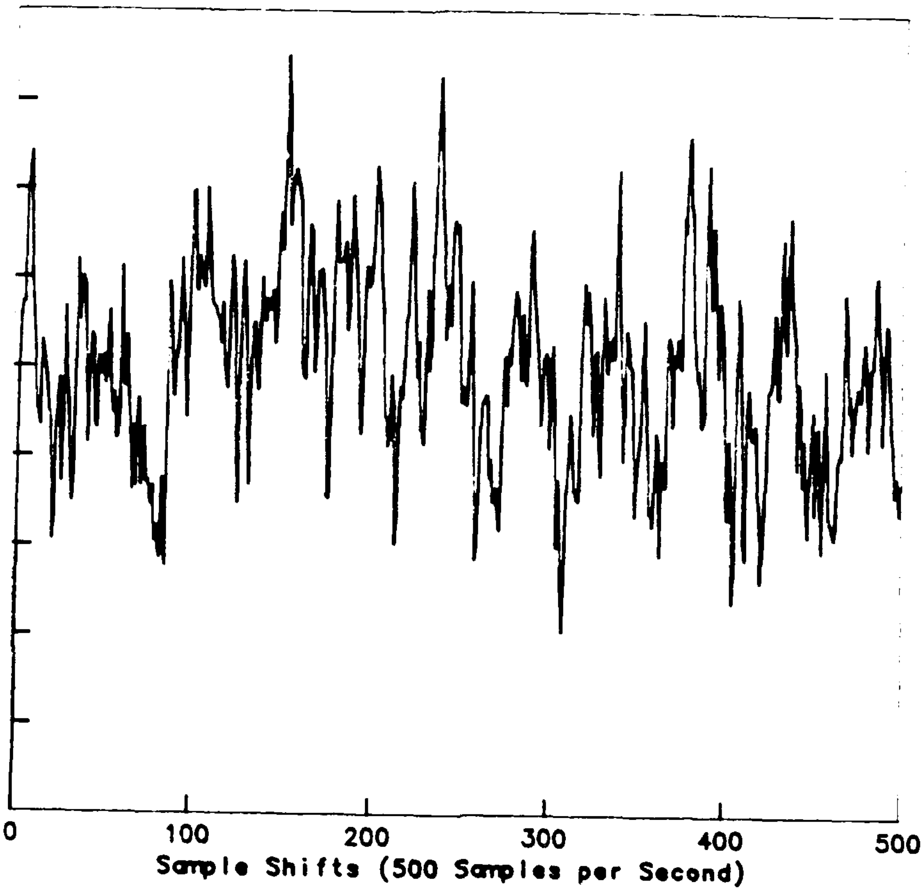

Figure 26. Calculated Impulse Response With Lights Covered (Subject #3)

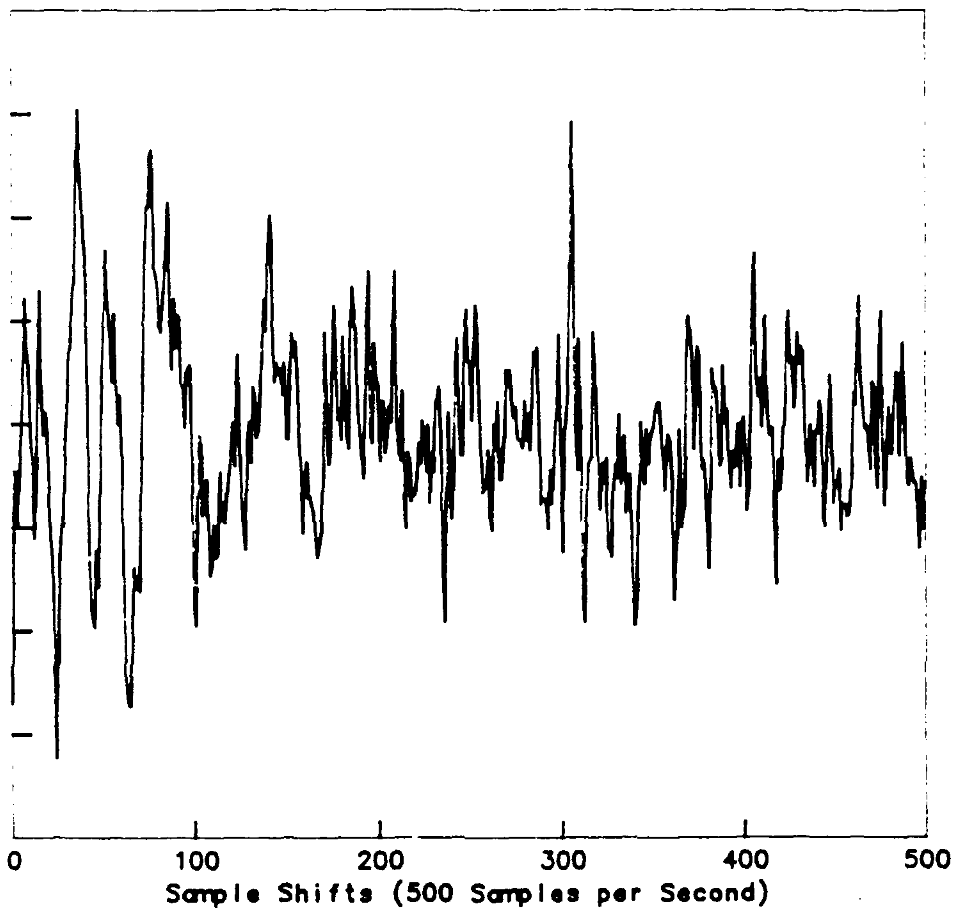

Figure 27. Average Impulse Response (Subject #4)

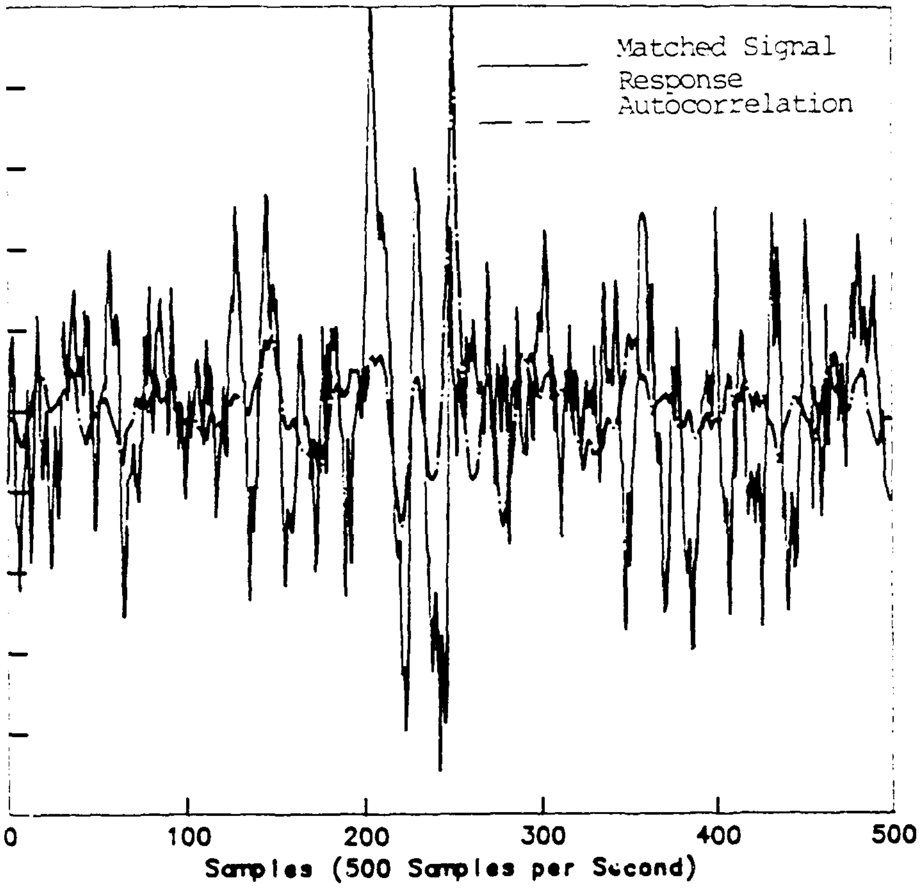

Figure 28. Normalized Matched Signal Response and Autocorrelation of Matched Signal (Subject #4)

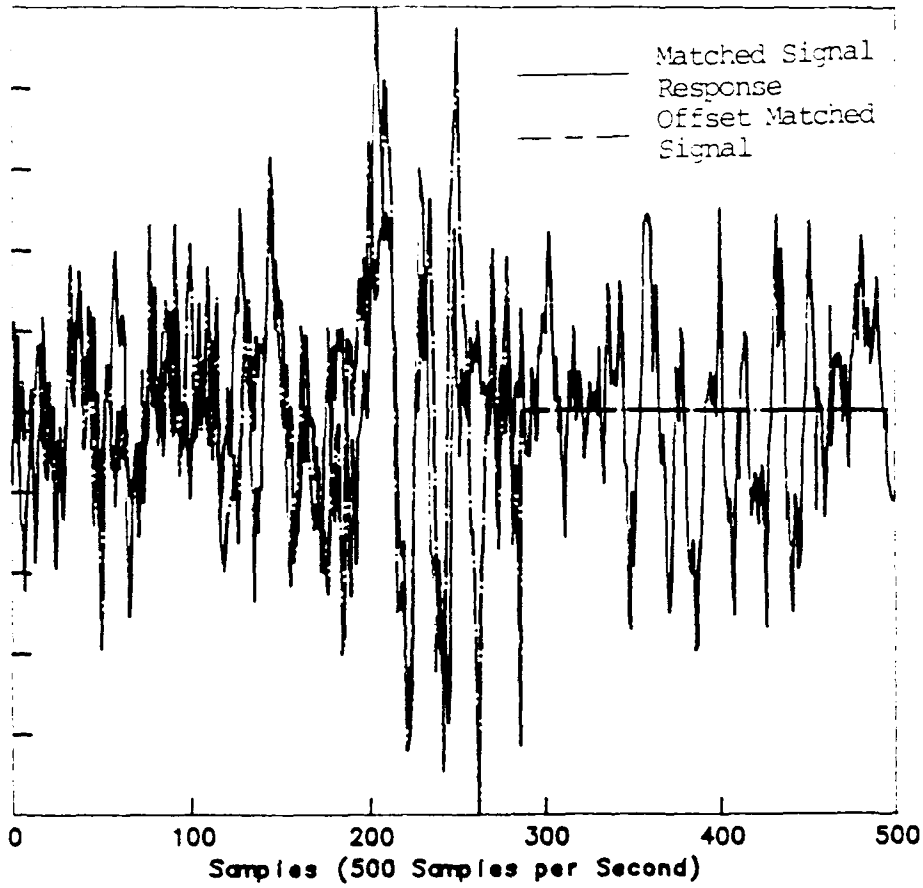

Figure 29. Normalized Matched Signal Response and Matched Signal Offset by 37 Samples (Subject #4)

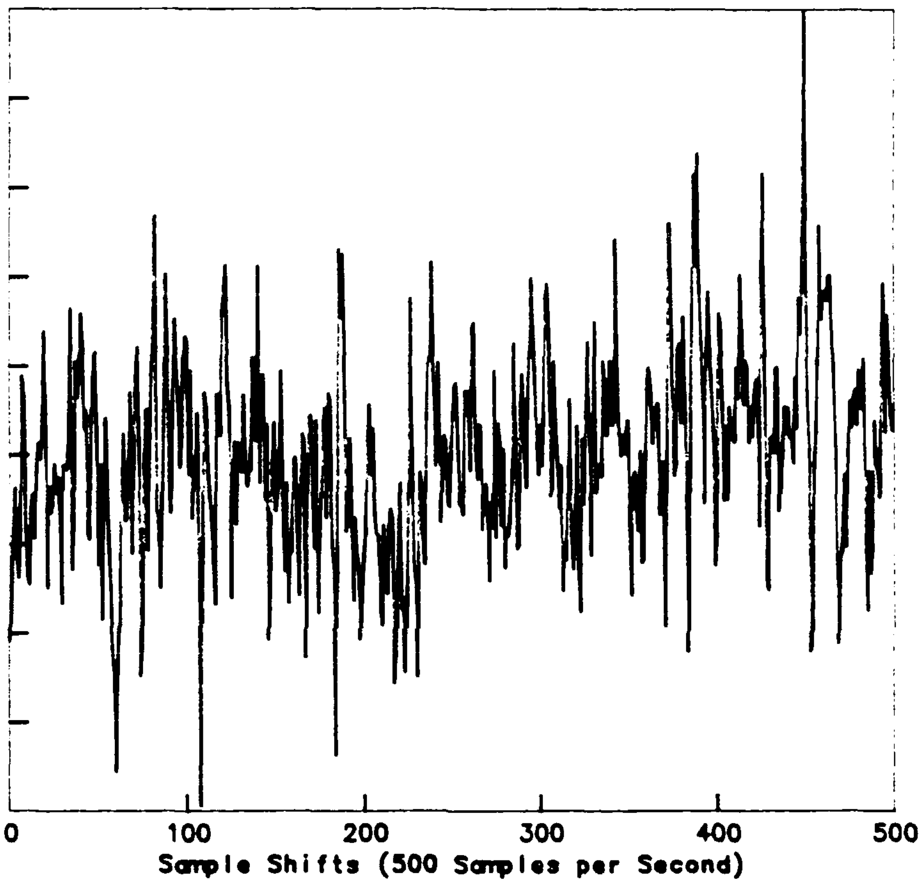

Figure 30. Calculated Impulse Response With Lights Covered (Subject #4)

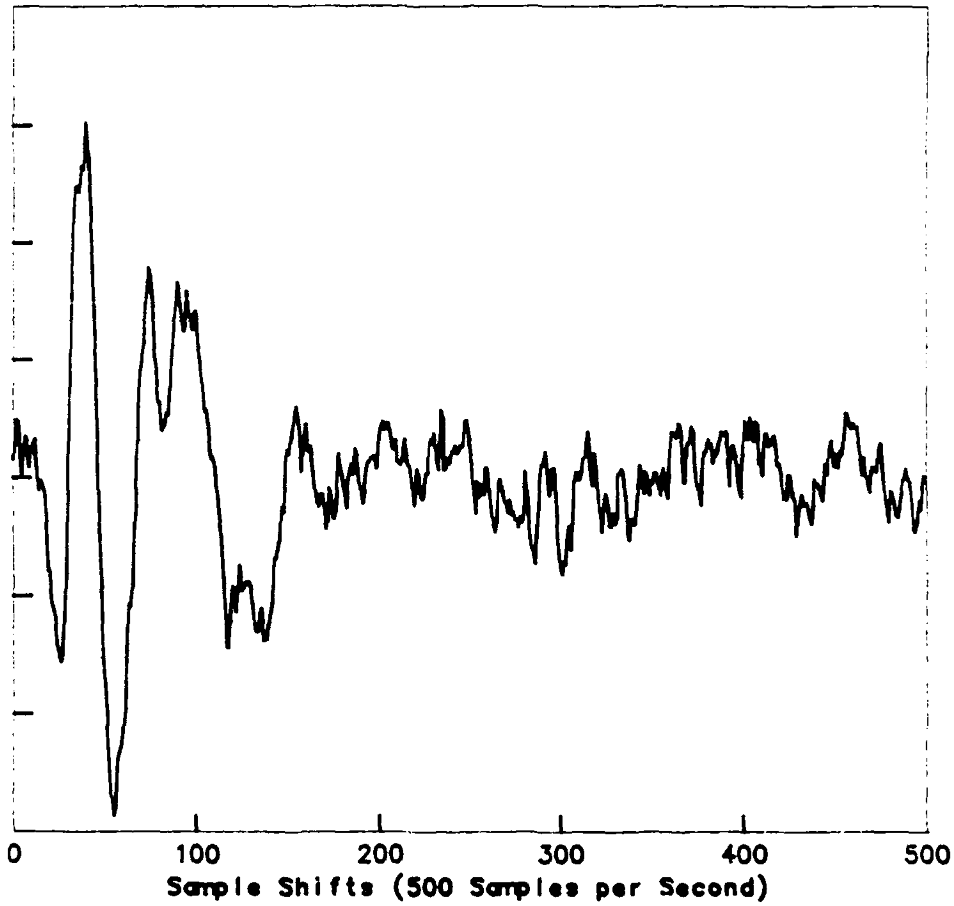

Figure 31. Average Impulse Response (Subject #5)

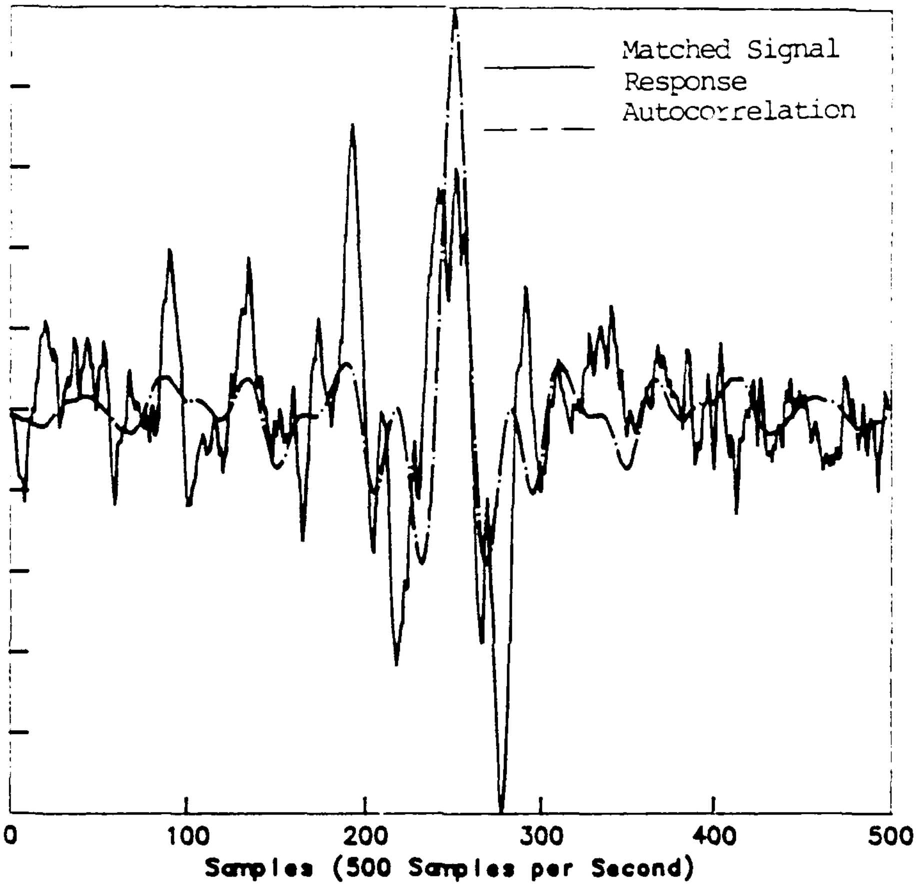

Figure 32. Normalized Matched Signal Response and Autocorrelation of Matched Signal (Subject #5)

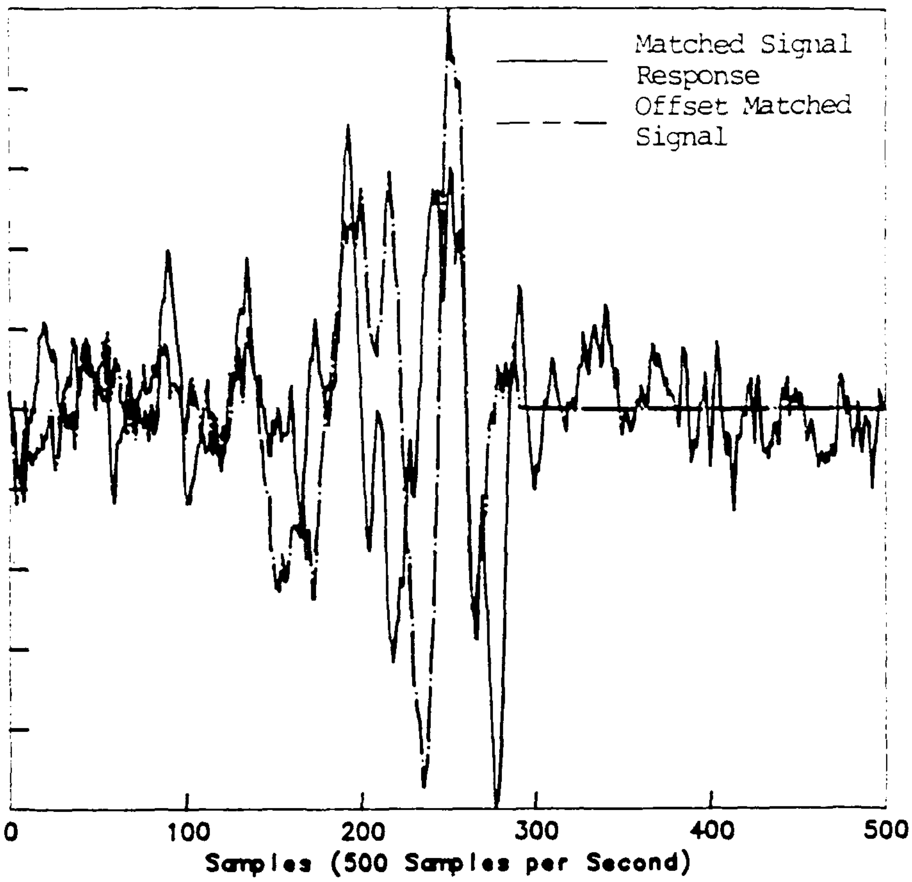

Figure 33. Normalized Matched Signal Response and Matched Signal Offset by 41 Samples (Subject #5)

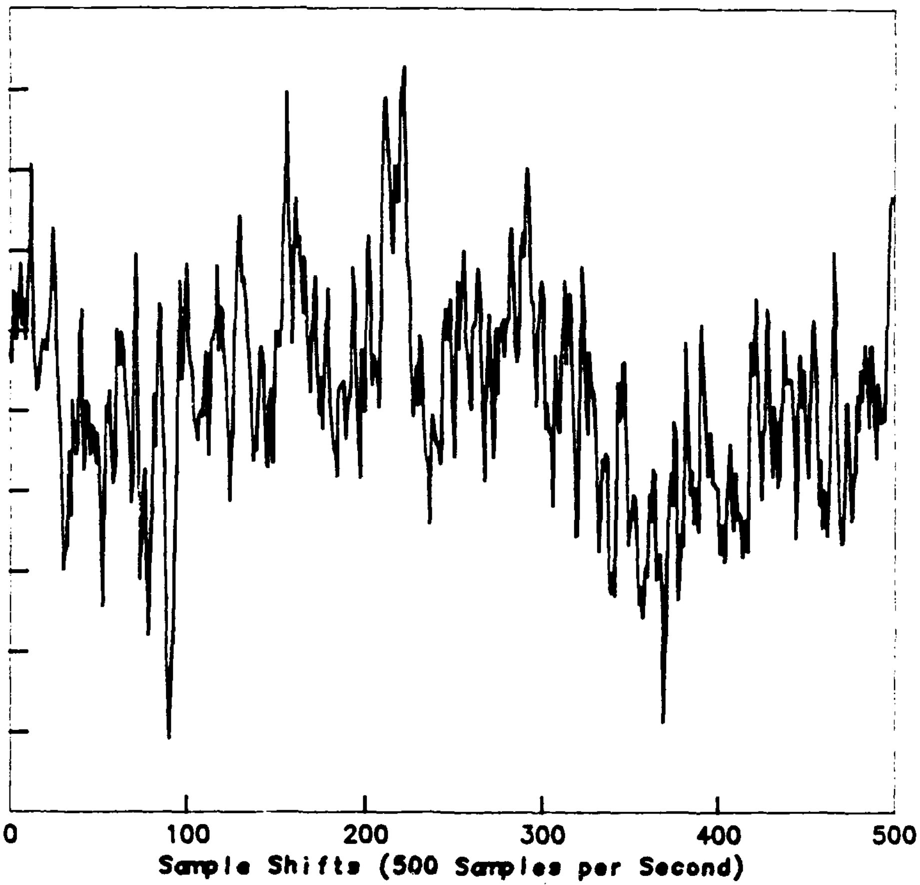

Figure 34. Calculated Impulse Response With Lights Covered (Subject #5)

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Vita

Captain Edward A. Colley ws [redacted] He graduated from North Syracuse Central High School in 1975. He served in the U.S. Army from April 1976 until April 1979 on active duty. He attended the Onondaga Community College and the Rochester Institute of Technology where he received the degree of Bachelor of Science in Electrical Engineering. After receiving his Bachelors Degree he attended the Air Force Officer Training School and was commissioned in March of 1984. His initial Air Force Assignment was with the Foreign Technology Division of the Air Force Systems Command at Wright Patterson Air Force Base. He started work at the School of Engineering, Air Force Institute of Technology, in June of 1988.

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This research applies random signal testing techniques to the human visual system. A binary maximal length sequence was used to modulate a flourescent light bank by about 15%. With this pseudo-random moise as a visual input, subjects were monitored with an electroencephalograph. The Cross-correlation between the pseudo-random inpur and the EEG output yields an estimate of the subject's visual system impulse response. An attempt was made to verify the impulse response using matche filter theory

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