EFFECT OF COHERENT MOVING STIMULUS ON THE VISUAL EVOKED POTENTIAL (CMVEP)

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ABSTRACT

This paper describes research on visually evoked potential by motion stimulus through the use of electroencephalography. The purpose was to investigate the human perception of coherent motion and incoherent motion by conducting experiments to determine the response to a coherent moving stimulus. The response was further verified by varying the stimulus parameters and using several different approaches, based on current understanding of the motion detection mechanism in the neural system. Positive results from the experiment provide further evidence for the proposed motion detection mechanism. Based on the results of the experiments, the properties of the coherent motion stimulus evoked potential are characterized.

1. INTRODUCTION

The brain's motion detection system has always been an interesting and challenging topic in neuroscience. The ability of neurons to characterize different types of motions plays an important role in building up the neural representation in animals. Because the inflow of information into the visual system is enormous, the brain has to rely on certain mechanisms to process and abstract the information. This process is known as visual perception.

An important aspect of visual perception is to group together objects moving at the same rate and direction. This characterization of coherent motion helps the animal to associate objects and to predict their movements.

In the past few years, considerable effort has been put into studying the motion detection mechanism of the neural system. Most research has been done on monkeys, not humans, because electrodes must be injected into the subject's brain. The research described in this paper avoids this problem by employing an electroencephalographic approach. Instead of directly inserting electrodes, this research measures the surface potentials at the scalp. So instead of an exact position within the brain being pinpointed, a global picture of the brain potentials is taken.

The analysis of the results obtained could provide insight into the motion detection mechanism, and could be used to verify proposed theories of brain motion analysis.

2. BACKGROUND

2.1 Origin of Scalp Potential

Scalp potentials recorded by the electroencephalograph (EEG) are generated in the cerebral cortex by pyramidal cells, a class of nerve cells. Because of their cellular orientation, pyramidal cells contribute more to the EEG than the second class of nerve cells, non-pyramidal cells. Pyramidal cells are oriented parallel to one another and their dendrites are perpendicular to the surface of the cortex, allowing for minimal signal attenuation (see Figure 1).

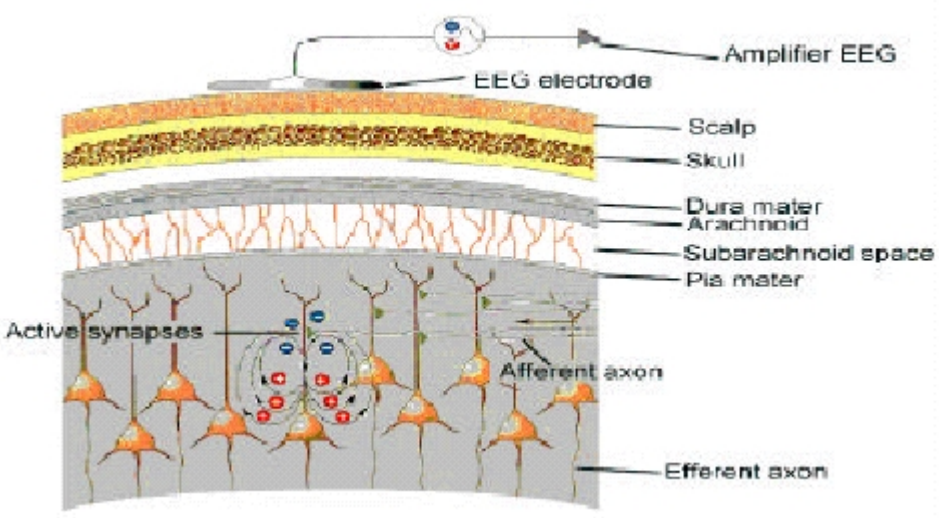

Figure 1: Pyramidal cells act as dipoles in the volume conductor of the head [2].

The apical dendrites of pyramidal cells are responsible for the generation of action potentials that amplify synaptic currents. Although action potentials are the largest signal generated by neurons, they actually contribute little to surface potentials. The main source of scalp potential recorded by the EEG results from extracellular current flow associated with summated synaptic potentials in the activated pyramidal cells. These synaptic potentials are slower than action potentials, a fact that allows more time for signal summation [1].

In addition to dendritic projections, the axons of pyramidal cells extend to other areas of the brain and spinal cord. Cellular projections that lie in a plane parallel to cortical layers play the most significant role in the generation of collective electrical activity. By facilitating the flow of synaptic currents through extracellular space, the axons are directly responsible for the measurable activity of cortical neurons [1].

Ionic current flow generated by the synchronous nerve cells through extracellular space can be described by the theory of volume conduction. For a single pyramidal cell, potential is produced when a current flows across the resistance of the cell membrane. Current flows inward through the synaptic membrane and outward along the extrasynaptic membrane. This inward and outward current flow creates a current sink on the negative side of the extracellular potential and a source at the site of outward current, so that the cells acts like a dipole (see Figure 2). [13]

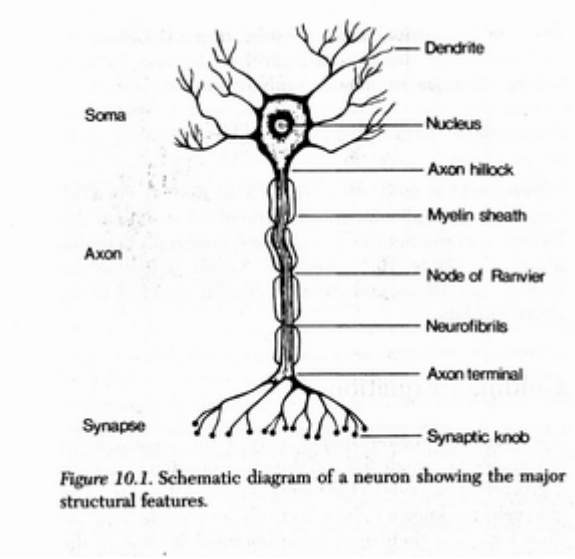

Figure 10.1. Schematic diagram of a neuron showing the major structural features.

Figure 2: Single neuron cell structure [13]

2.2 Measurement of Scalp Potential

An electrode placed on the scalp records the summed signal from many cells. Depending on the orientation of the combined dipoles, the potential recorded at the scalp is either positive or negative. The recorded signal comes principally from neurons near the tip of the electrode and only to a small extent from more distant neurons. As the electrode is moved from the source of activity, the signal decreases by the square root of the distance. This rapid drop in potential combined with the large resistance of the scalp, skull, and cerebrospinal fluid surrounding the brain results in a measured scalp potential that is very small. The frequencies of the potentials recorded from the surface of the scalp vary from 1 to 30 Hz, with amplitudes ranging from 20 to 100 μV [1].

2.3 The Visual System

Visual information required to construct this representation of the world comes in through the eyes and is projected on the retina. Then the optic nerve sends this information to the thalamus, which passes it up to the primary visual cortex (called V1), where simple aspects of the visual scene are first analyzed. Information is then projected out to cortical areas around the primary visual cortex, and they perform more elaborate processing of the visual image. This is where the more complicated cognitive functions take place [2] (see Figure 3).

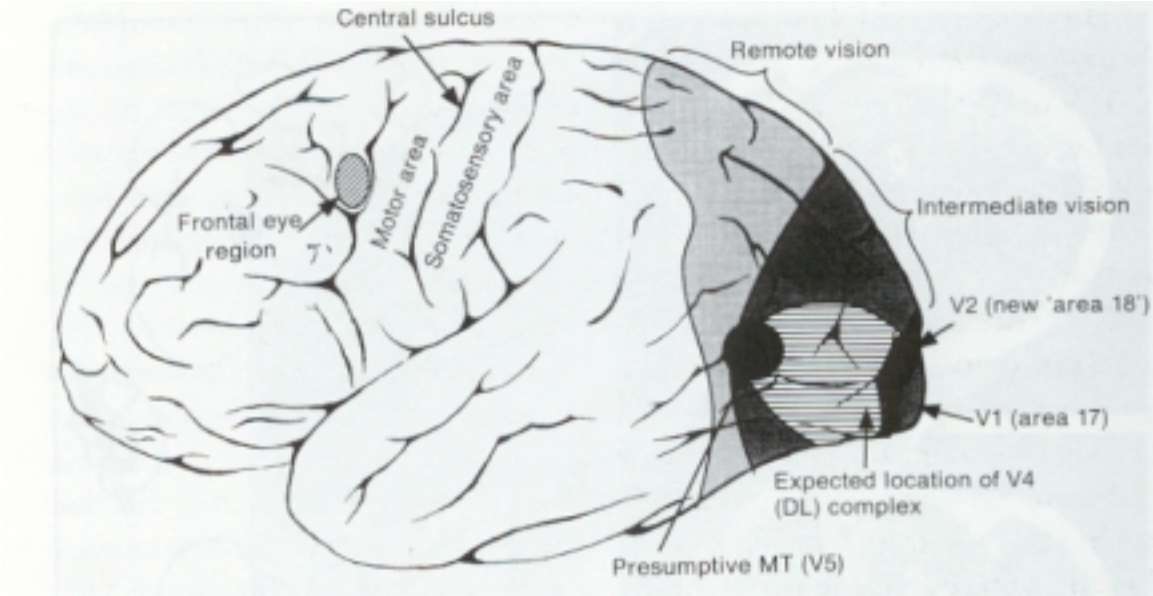

Figure 3: The location of some of the important visual functions in the human visual cortex. V1, the primary visual cortex, also called the striate cortex; V2, visual area 2; V4, visual area 4; MT, middle temporal, also called visual temporal or visual area 5. [1]

The visual system can be divided into two or more separate pathways. The two main pathways: the parvocellular (P) pathway and magnocellular (M) pathway. The P pathway splits to produce two new pathways in the upper layers of V1. One pathway seems to deal primarily with color and this is called the P-B pathway. Neurons in the second pathway are sensitive to features such as the orientation of the stimulus and seem to mediate high acuity perception. [3, 11]

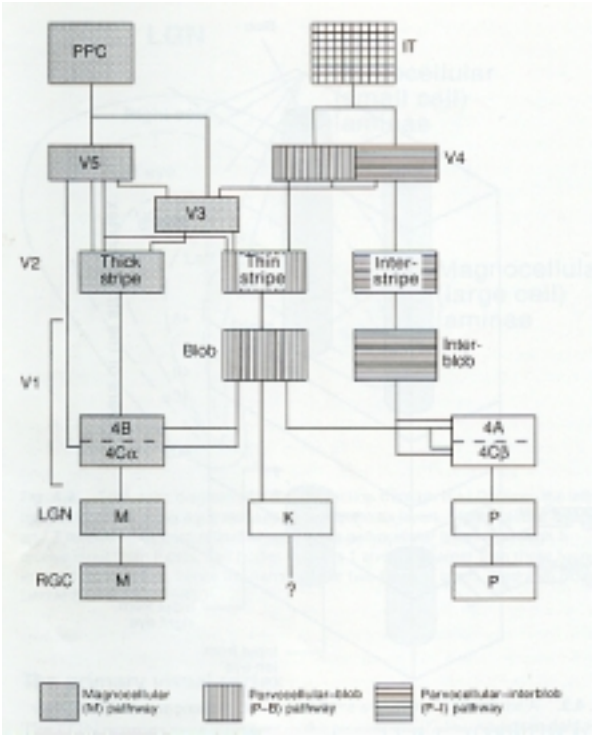

Figure 4: Subcortical and cortical pathways in the macaque monkey. [4]

2.4 Motion Detection Mechanism

MT is an important area in the processing of visual motion information. Area MT receives input from a number of other cortical areas such as V2 and V3, but it is also directly innervated by cells in V1. MT is most notable for the fact that almost all its cells are direction-selective, unlike areas earlier in the parietal stream or anywhere in the temporal stream. The neurons in MT respond to types of motion, such as drifting spots of light, that are not good stimuli for other areas. For these reasons, MT appears to be specialized for the analysis of motion.

Neurons in area MT have large receptive fields that respond to stimulus movement in a narrow range of directions. These direction-selective cells are arranged into a system of columns. The perception of movement at any point in space depends on a comparison of the activity across these direction columns [5].

2.5 Contrast Response Analysis

Before the coherent motion experiments were done, a number of experiments were performed using a contrast response stimulus. Because it had been used in previous research, the contrast response stimulus served as a good training material for the subjects to learn to focus and attend to a target on the computer screen.

Figure 5 shows the stimulus set-up. The stimulus was a wedge-shaped pattern that flickered at a fixed frequency. The subject had to fixate at the center of the screen while attending to the flickering wedge during the experiment. Figure 6 shows one set of results

obtained using a stimulus frequency of 7.5 Hz with the flickering wedge set at a contrast of 25%.

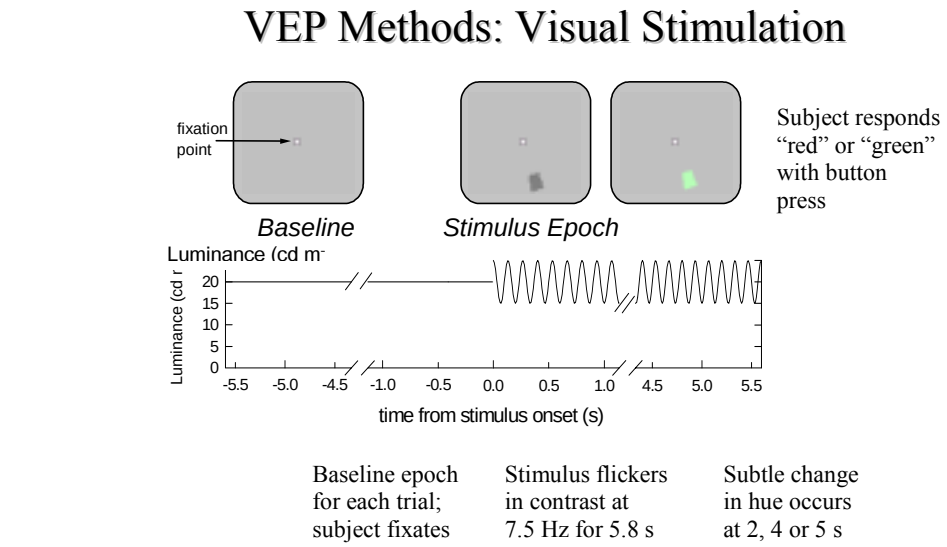

Figure 5: Stimulus set-up for contrast response stimulus

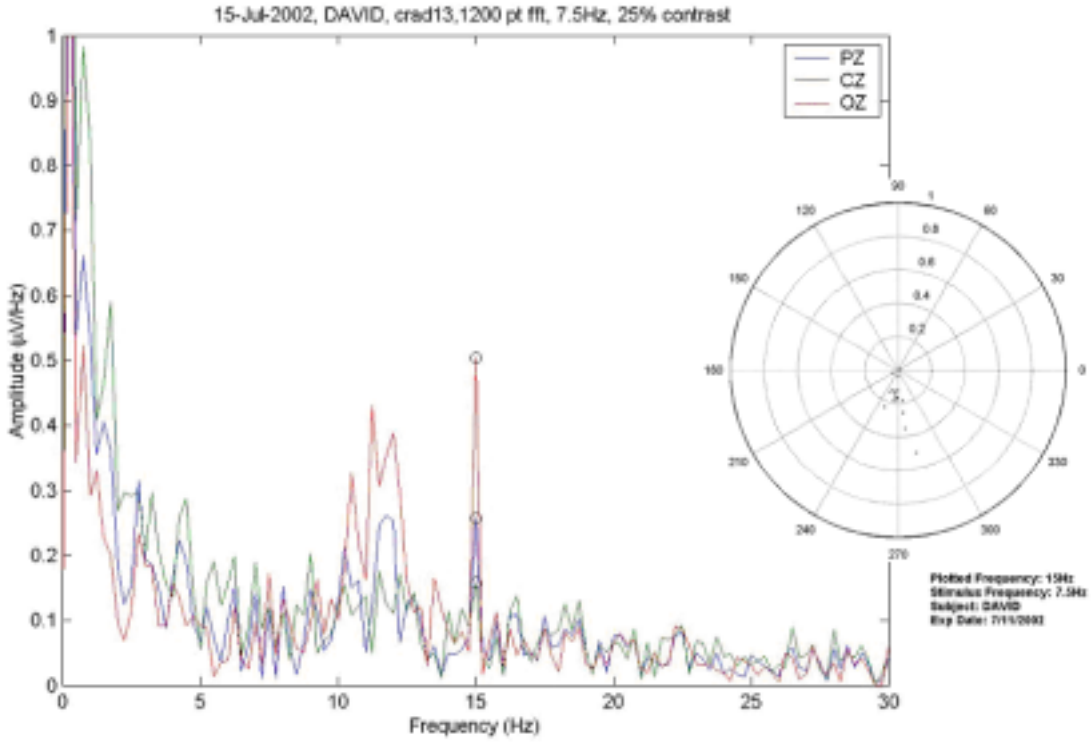

Figure 6: Results in Frequency domain and the corresponding polar plot. Stimulus flickering at 7.5 Hz with 25% contrast.

3. METHODS

3.1 Subjects

The subjects for the experiments were David Pugh, Rebecca Weldon and Adrian Lau. All had been trained in doing the contrast response stimulus experiment.

3.2 Experimental Set-up

The experimental set-up consisted of four computers: a master PC to collect EEG data using the software InstEP, a slave PC to aid in synchronization in the system, a Macintosh to run the contrast response stimulus video, and a PC to run the coherent moving dots stimulus. The monitor presenting the stimulus sat behind a metal shield to prevent the magnetic field from interfering with the EEG apparatus. All electronic equipment was grounded.

The subject sat in a chair, head in a chin rest, viewing the stimulus on the monitor through a rectangular hole in the metal shield. The chin rest was set to ensure that the subject's eye level was horizontal to the center of the monitor. The distance of the subject's eyes from the center of the monitor was kept at 50cm. The EEG apparatus consisted of an electrode cap, a pre-amplifier, and a main amplifier. The pre-amplifier was connected to the electrode cap and the main amplifier, and the main amplifier was connected to the PC.

The subject wore an electrode cap with 16 electrodes positioned over specific places on the scalp, 2 separate electrodes placed behind the ears, an electrode beneath the left eye, and an electrode at the right of the right eye. The electrode cap was held secure by short straps fastened to a chest strap. The recorded potentials were amplified 10,000 times, filtered at 0.01–100 Hz, and sampled at 300 Hz. Before each experiment, electrode gel was inserted into each electrode with a blunt syringe until all electrode impedances fell below 5.0 μΩ. The electrode impedances were recorded and the subject's placement was precisely adjusted.

3.3 Stimulus Design

The stimulus was designed using Matlab and the PsychToolbox [6, 7]. The program was separated into two parts. One part was used to create the stimulus video before experiments, and the other part was used to display the stimulus during experiments. The division was needed because creating the video required a great many computations. To prevent delays during the display of stimulus, the videos were created off-line beforehand.

The stimulus was displayed on a 15-inch monitor using a resolution of 640 × 480. The refresh rate of the monitor was set to 75 Hz. The stimulus was designed with a square box at the center of the monitor showing approximately 900 randomly placed dots (see Figure 7). A percentage of the dots moved coherently, and the rest moved randomly. For the coherent motion of the dots, a simple harmonic motion was employed. In the stimulus, the coherently moving dots moved in phase with the same frequency and amplitude; the other dots moved randomly at a speed matching the average speed of the

oscillating dots. The dimensions of the square box in the stimulus subtended to a visual angle of 17.2°. Each dot was one pixel in size. According to research by W. A. van de Grind [10], the human visual system is most aware of dots moving with speed at around 10 degrees of visual angle per second (dva/s). When the stimulus frequency was at 7.5 Hz and with an amplitude of 4 pixels, the oscillating motion had a maximum speed of 10.8 dva/s. (Figure 7 shows the stimulus)

The stimulus was synchronized with the data collection system through the display of an on/off signal on the presentation monitor. The on/off signal activate/deactivate a photodiode attached to the monitor, sending signals about the on/off status of the stimulus to the data collection system.

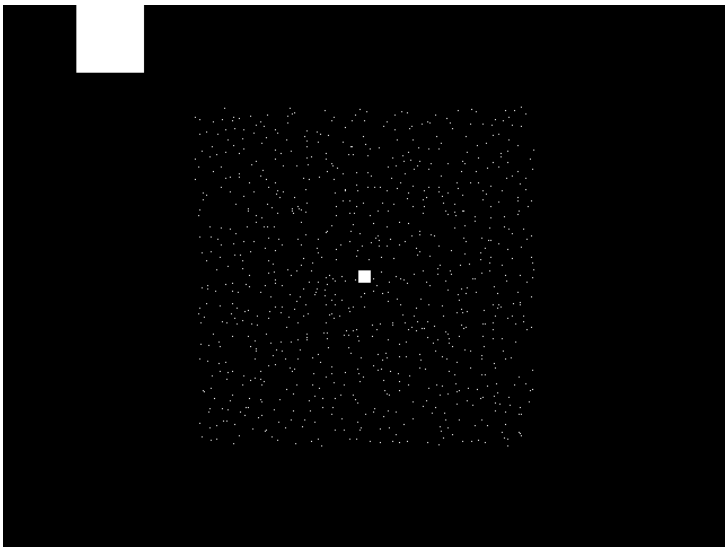

Figure 7: Stimulus of coherent moving dots on the presentation monitor. The small square at the center of the monitor was the fixation point. The top-left square on the monitor was showing the on/off signal for synchronization. The photodiode was attached exactly at that location on the monitor.

Originally the experiment included a psychophysical task: The subject had to state the direction of the coherent motion. The idea behind the task was to let the subject focus and attend to the target. However, even at low percentages of coherence it was still easy for the subject to tell the direction of coherent motion. Moreover, subjects reported they could easily focus on and attend to the motion of dots even without the aid of a psychophysical task. Hence the task was taken out of the experiment.

3.4 Data Analysis

The experimental data was collected in terms of blocks of trials. One trial was the time from 1 second of baseline period before the onset of the stimulus until 5 seconds after the beginning of the stimulus (see Figure 9a). One block of trials was the continuous collection of 32 trials displayed one after the other. In a typical experiment, 7–9 blocks of trials were recorded. In each block of trials, the percentage of coherence was kept constant, while the coherent motions changed randomly in 4 different directions (0°, 45°, 90°, and 135°).

Figure 9b shows the time scale data recorded with electrode POz, averaged over 96 trials. The stimulus conditions were 80% of coherence, 7.5 Hz stimulus frequency. The baseline epoch exhibits a 10 Hz oscillation. After stimulus onset there is a biphasic transient that lasts about 1s, followed by an approximately steady oscillation, whose frequency is 15 Hz, the second harmonic of the stimulus.

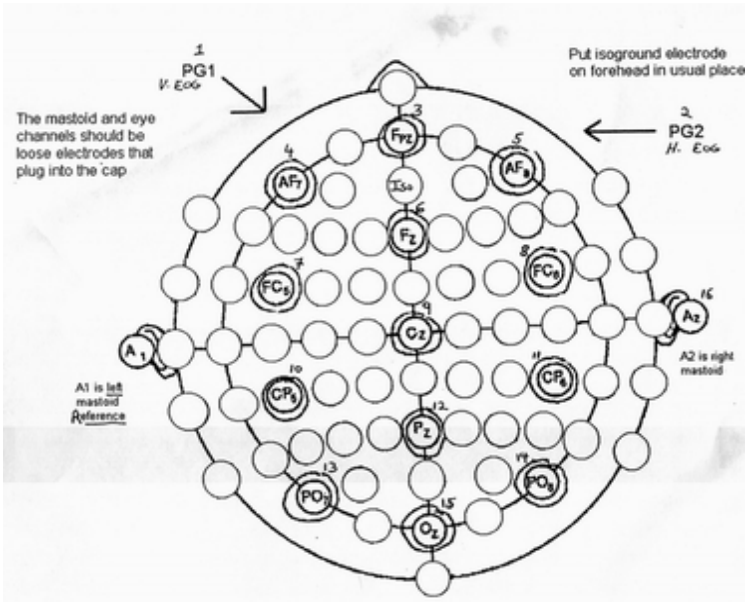

Figure 8: Diagram showing the position of the 16 electrodes on the scalp

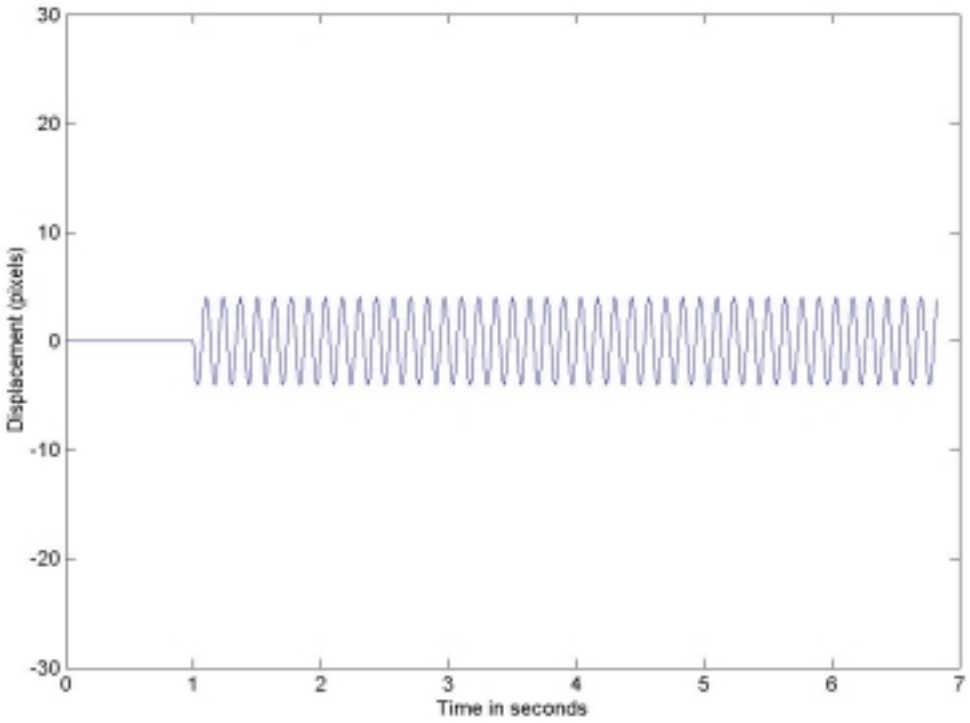

Figure 9a: Stimulus status with respect to time in a trial

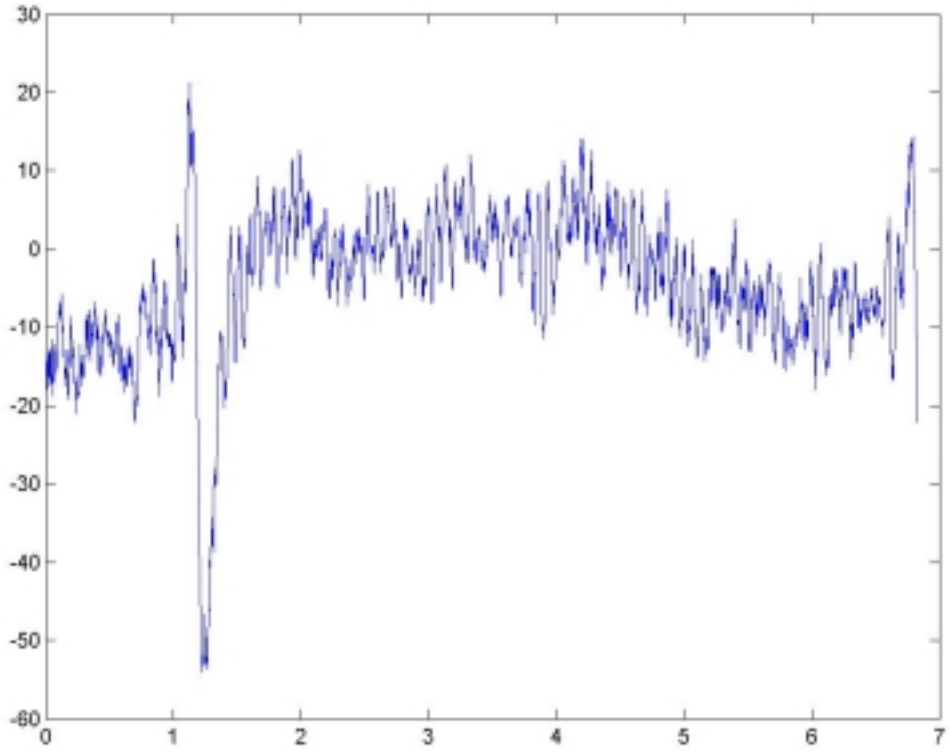

Figure 9b: time scale data recorded with electrode POz. (80% of coherence, 7.5 stimulus frequency)

The blocks of data were analyzed using Fast Fourier Transform (FFT) in Matlab. Figure 9c presents two Fourier spectra of the time epoch between 1s and 5s. The two spectra were obtained by averaging the spectra of the 96 individual trials in two different ways. In the first method of averaging (red trace), the FFT of each trial's data was computed and the magnitudes were averaged; this method neglects the phase difference between trials, and reveals the underlying EEG noise, including the large alpha component at around 10 Hz. In the second method (blue trace), the FFT of each trial's data was computed and the complex average was taken before obtaining the magnitude for the plot. This second method of averaging preserves the phase relation of each Fourier frequency component in each trial.

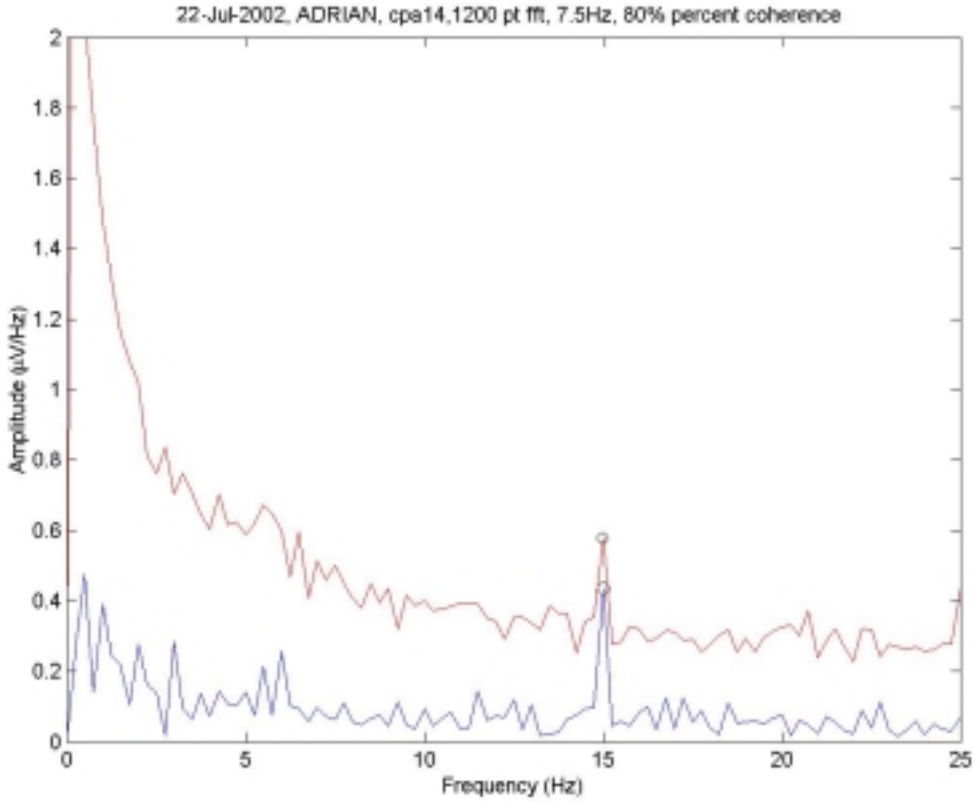

Figure 9c: Fourier spectra of the time epoch between 1s and 5s of the same data as shown in figure 9b.

Comparing the 15-Hz peaks of the two methods of averaging (red and blue traces), the responses give statistically indistinguishable magnitudes. Throughout the rest of this paper the second method of averaging is used because of its utility in isolating small CMVEP responses, and also because of its value in filtering off out-of-phase signals.

3.5 Verification of Experimental Results

In order to prove that the peak obtained was really caused by the coherent motion but not by other factors that appeared on the stimulus, three variations in the stimulus were propose. The first was to vary the stimulus frequency. The second was to lower the contrast difference between the dots and the background. The third was to test with the motion adaptation approach.

3.5.1 Varying Stimulus Frequency

The stimulus frequency (frequency of oscillation of the coherent moving dots) was changed to 6 Hz instead of the 7.5 Hz used in other experiments. The results showed a sharp peak at the second harmonic of the stimulus frequency. Showing that the peak shifted with the change in stimulus frequency would prove that the stimulus frequency was the sole cause of the peak in the results.

3.5.2 Lowering Contrast Difference

The contrast difference between the dots and the background was lowered from 100% to 60% (see Figure 10). According to research by E.D. Grossman and R. Blake, the detection of coherent motion is unperturbed so long as dot size and density are sufficient to support spatial resolution of the motion tokens [9]. Since the lowering of the contrast difference to 60% satisfied this condition, if the magnitude of the peak remained unchanged, the peak must be caused by coherent motion in the stimulus.

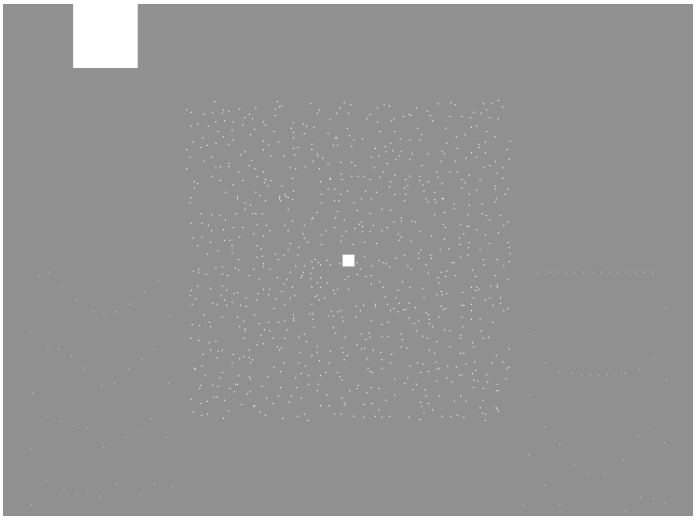

Figure 10: One frame of the coherent moving dots stimulus with contrast difference between the dots and the background lowered from 100% to 60%.

3.5.3 Testing with Motion Adaptation Approach

In the motion adaptation approach, stimuli with a fixed percentage of coherence moving in the same direction were shown to the subject for a long period of time. Then the subject was shown a few stimuli with the same percentage of coherence but perpendicular to the ones shown before. This approach was based on the fact that motion detecting neurons are direction-selective, with neurons sharing similar preferred directions clustered together in columns [8]. After a series of trials in the same direction, the neurons responsible for the direction would become adapted to the stimulus in that direction. When the direction changed suddenly, the neurons corresponding to the new direction are not yet adapted to the new direction of motion, and thus the response obtained should be weak. Hence if the data obtained showed that the response activity was lower when the direction was changed, then the response must be caused by the coherent motion in the stimulus.

4. RESULTS

A sharp peak was obtained at the second harmonic of the stimulus frequency. As seen in Figure 11a, a sharp peak occurred at 15 Hz from a stimulus with 80% of coherence and stimulus frequency of 7.5 Hz. Figure 11b shows the result from a control

stimulus with 0% of coherence. The absence of peak in that figure is evidence that the coherently moving stimulus was the cause of the peak.

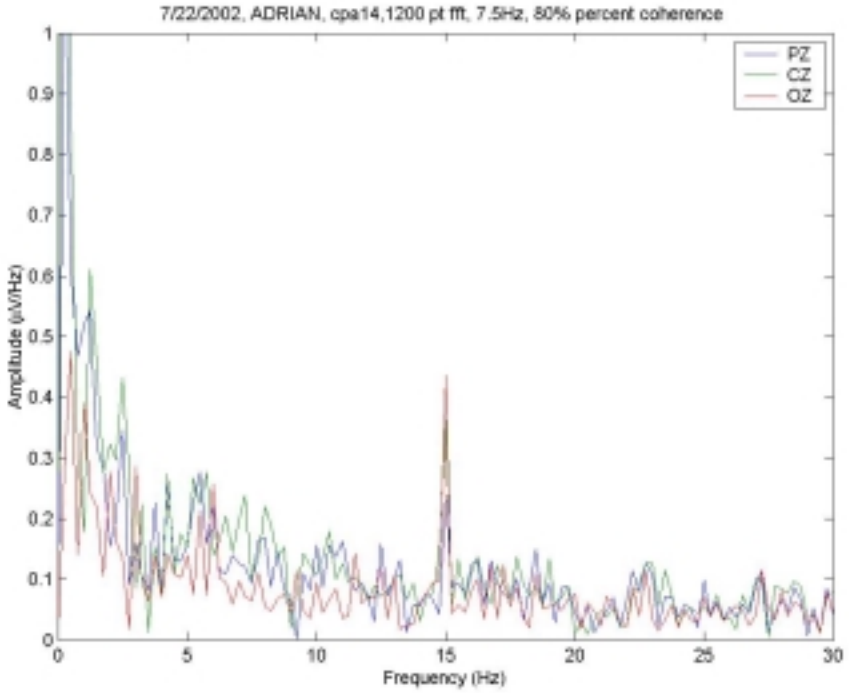

Figure 11a: Fourier spectrum with stimulus parameters: 80% of coherence, stimulus frequency at 7.5 Hz.

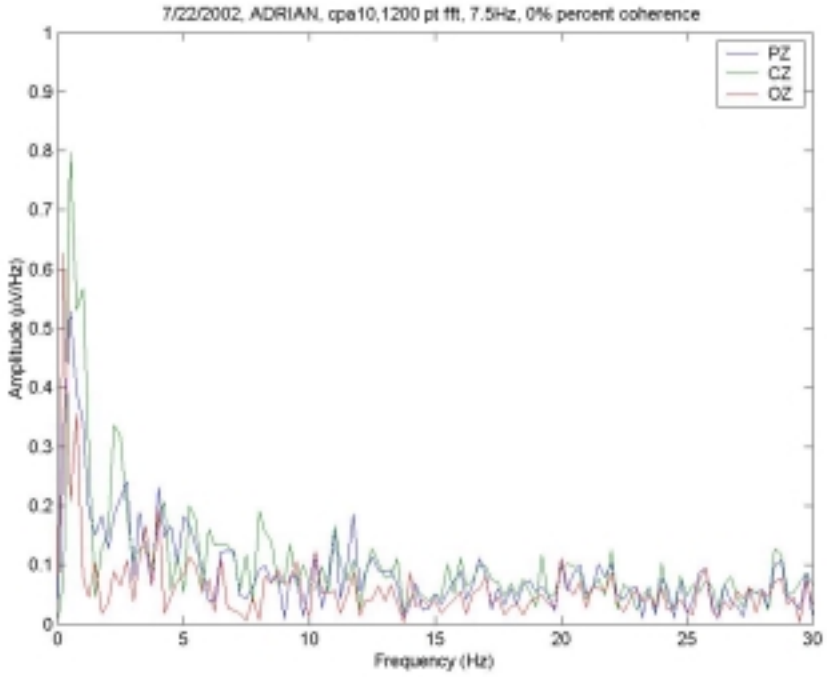

Figure 11b: Fourier spectrum with stimulus parameters: 0% of coherence, stimulus frequency at 7.5 Hz (none of the dots were in oscillation)

The response to the coherent moving dots stimulus is highly synchronous over the scalp. The sharp peak in Figure 11a shows that the response is highly synchronous. Since the graph was obtained from the complex average of the FFT results, the phase differences were taken into account. The relatively high magnitude of the peak shows that the phase differences of the 15-Hz components were so small that they did not cancel each other out. Figure 11c presents the polar plot of the phases of all 16 electrodes at the frequency of 15 Hz. The majority of the electrode plots lay around the 60° line on the polar graph, showing that the scalp potential oscillated in a highly synchronous manner at 15 Hz.

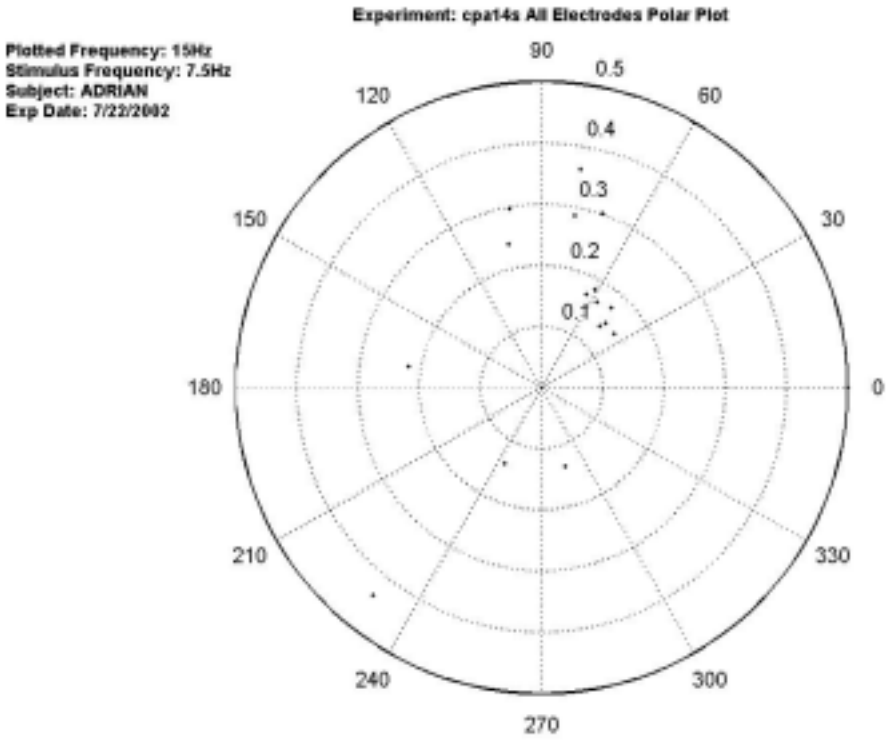

Figure 11c: Polar plot of the phases of all 16 electrodes at the frequency of 15 Hz.

A higher percentage of coherence gave rise to higher magnitude at the 15-Hz peak. Figure 12 shows the magnitude of the peak against the percentage of coherence in an experiment. As the percentage of coherence rose, so did the magnitude of the peak. Hence the figure shows that noises in the stimulus lower the synchronous level of the response.

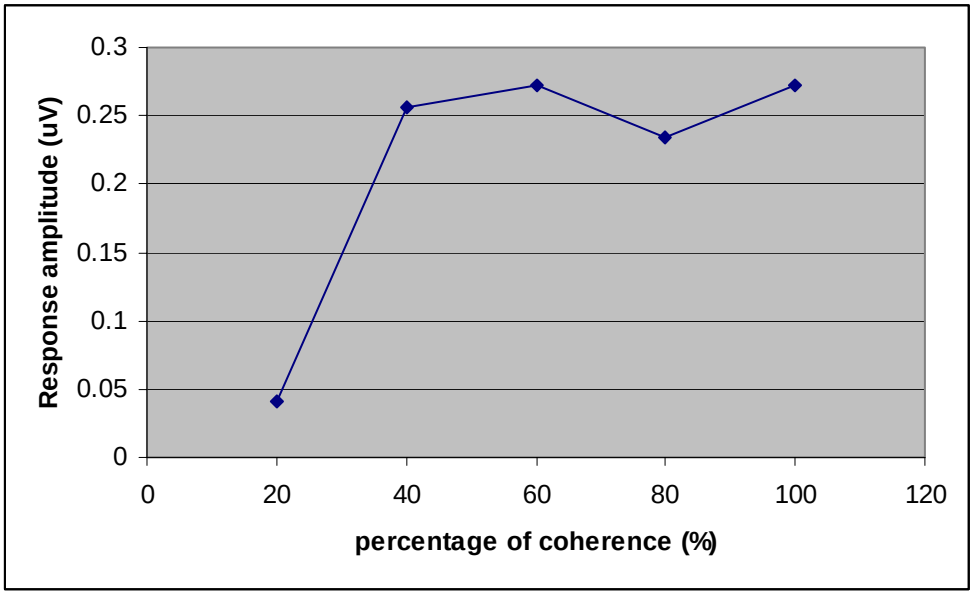

Figure 12: The plot of the magnitude of the peak against the percentage of coherence in an experiment.

Variation in stimulus frequency shifted the position of the peak correspondingly. Figure 13 shows the FFT results after the stimulus frequency was shifted from 7.5 Hz to 6 Hz. The peak in the plot was shifted from 15 Hz to 12 Hz, which was the second harmonic of the 6-Hz stimulus frequency. A comparison of the figures shows that the oscillation frequency of the moving dots stimulus was the cause for the synchronous manner of the response.

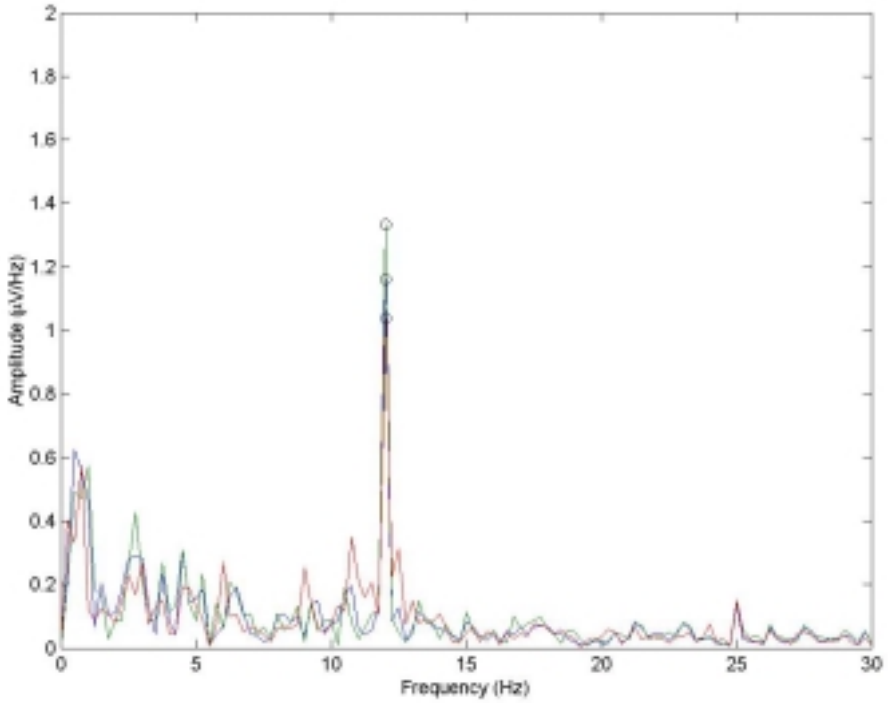

Figure 13: Fourier spectrum of the experiment ran under the condition: 80% of coherence, 6 Hz stimulus frequency

Lowering the contrast difference in the stimulus affect the magnitude of the peak. As opposed to the prediction that the magnitude would remain unchanged, the results showed that a reduction in contrast difference decreased the magnitude of response. Figure 14a shows the plots of results from high contrast (100% contrast) and Figure 14b from low contrast (60% contrast). Both experiments used a stimulus frequency of 7.5 Hz, and 80% of coherence. The two graphs both peak at 15 Hz but it is obvious that the magnitude of the response was lower in Figure 14b. Subjects reported that the high contrast difference stimulus was easier to attend to. The approach might not be reliable, because the attention level of the subject was not a fixed factor, and it contributed to the reduction in the magnitude of response.

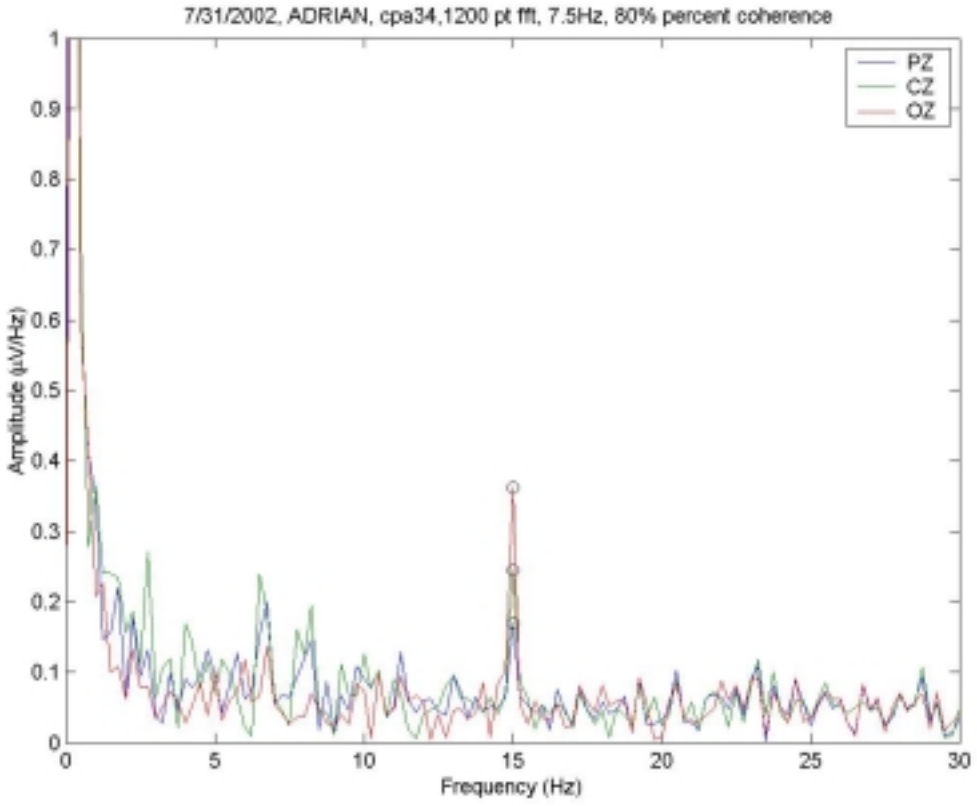

Figure 14a: Fourier spectrum of the experiment ran under the condition: 80% of coherence, 7.5 Hz stimulus frequency, 100% contrast difference

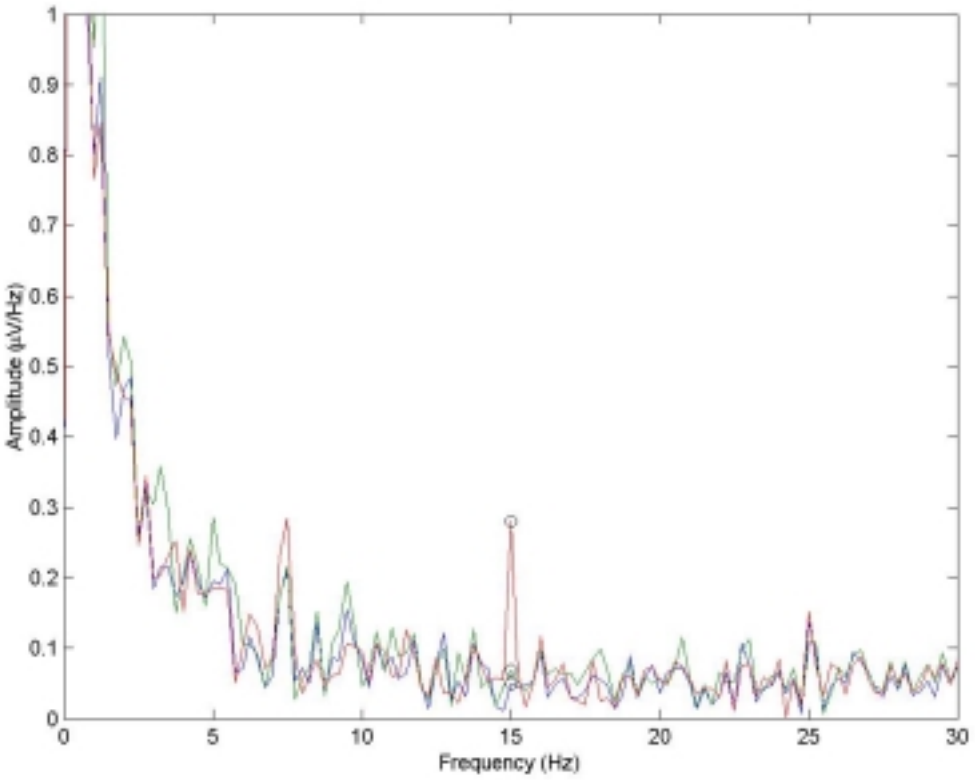

Figure 14b: Fourier spectrum of the experiment ran under the condition: 80% of coherence, 7.5 Hz stimulus frequency, 60% contrast difference

The motion adaptation approach was not carried out in this research because of time constraints. In order to obtain a reliable statistical result from the motion adaptation approach, many trials would be needed

5. DISCUSSION AND CONCLUSION

If the project is continued, the motion adaptation approach will be a priority. The results will provide insight into the direction-recognition mechanism in the neural system.

Although the motion adaptation approach was not carried out, the results from the other approaches provided strong evidence that the synchronous response was evoked by the coherent motion in the stimulus.

Based on the results of the experiments, the coherent motion visual evoked potential (CMVEP) can be characterized in the following five ways:

1. The CMVEP occurred at the second harmonic of the stimulus frequency.
2. The CMVEP is highly synchronous over the scalp.
3. A higher percentage of coherence gave rise to a higher response.
4. Variation in stimulus frequency shifted the position of the response correspondingly.

One of the interesting results was that the response occurred at the second harmonic of the stimulus frequency. This may be due to the direction detection mechanism in the neurons. The direction-selective cells are arranged in a system of columns (see section 2.4). In the oscillating motion in the stimulus, the coherent dots' movement in one direction would "turn on" the corresponding direction-selective cells; the dots' movement in the opposite direction would "turn on" the other corresponding cells. In a cycle of oscillation, the dots will move in one direction half of the time and in the opposite direction the other half. In other words, the rate of change of directions is two times the frequency of oscillation. Hence when the on/off signals of the neurons are combined and rectified in the neural system, the response obtained will be double the frequency of the stimulus.

6. RECOMMENDATIONS

A possible extension of this project is to determine the psychometric function of the subject in detecting the direction in the coherent motion stimulus. By varying the percentage of coherence in the stimulus, the threshold where the subject is uncertain about the direction of motion could be measured. An efficient way to determine the threshold value is to use the QUEST staircase procedure [12], a response-directed method of obtaining the threshold. Attaining such results will aid in determining the subject's sensitivity to direction detection.

Another possible extension to the project is to alter the way the stimulus is presented. Instead of showing a large box of moving dots at the center of the screen, a small box at a fixed eccentricity could be used to present the moving dots. Results obtained could be directly compared with the results from the contrast response experiments.

7. ACKNOWLEDGMENTS

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