ABSTRACT

LABVIEW-CONTROLLED STIMULUS PRESENTATION ON A MONITOR FOR SMOOTH PURSUIT EYE MOVEMENT EXPERIMENTS

by
Florence Bautista Chua

Smooth pursuit is an example of how movements in the visual world guide involuntary oculomotor movements. A current system to study eye movements uses an oscilloscope screen. A computer screen offers many advantages: a greater visual field, the use of shapes, 32 bits of colors, and increased timing accuracy. To control stimulus display on a computer monitor, instrumentation was developed in LabVIEW. Initial studies supported a draw/redraw to erase method for stimulus presentation. An experiment compared the computer monitor to the oscilloscope. Indeed, the monitor display was an improvement over the oscilloscope for vision research.

LABVIEW-CONTROLLED STIMULUS PRESENTATION ON A MONITOR FOR SMOOTH PURSUIT EYE MOVEMENT EXPERIMENTS

by
Florence Bautista Chua

**A Thesis
Submitted to the Faculty of
New Jersey Institute of Technology
in Partial Fulfillment of the Requirements for the Degree of
Master of Science in Biomedical Engineering**

Department of Biomedical Engineering

May 2003

Blank Page

APPROVAL PAGE

LABVIEW-CONTROLLED STIMULUS PRESENTATION ON A MONITOR FOR SMOOTH PURSUIT EYE MOVEMENT EXPERIMENTS

Florence Bautista Chua

Dr. Tara L. Alvarez, Thesis Advisor — Date
Assistant Professor of Biomedical Engineering, NJIT

Dr. Stanley Reisman, Committee Member — Date
Professor of Biomedical Engineering, NJIT

Mr. Michael T. Bergen, Committee Member — Date
VA New Jersey Health Care Center, East Orange, New Jersey
Adjunct Professor of Biomedical Engineering, NJIT

Dr. Richard J. Servatius, Committee Member — Date
Associate Professor of Neuroscience, UMDNJ

BIOGRAPHICAL SKETCH

Author: Florence Bautista Chua

Degree: Master of Science in Biomedical Engineering

Date: May 2003

Graduate and Undergraduate Education:

- Master of Science in Biomedical Engineering
  New Jersey Institute of Technology, Newark, New Jersey, 2003

- Bachelor of Science in Engineering Science
  New Jersey Institute of Technology, Newark, New Jersey, 2000

Major: Biomedical Engineering

Presentations and Publications:

F.B. Chua, A. Daftari, T.L. Alvarez, R. DeMarco, M.T. Bergen, K.D. Beck, R.J. Servatius,
"Effect of Light Flashes on Saccadic Oculomotor Control",
Proceedings of the IEEE 29th Annual NorthEast Bioengineering Conference, Newark, NJ, Mar. 2003.

A. Daftari, T.L. Alvarez, F. Chua, R. DeMarco, K. Ciuffreda,
"The Dynamics of Convergence Insufficiency",
Proceedings of the IEEE 29th Annual NorthEast Bioengineering Conference, Newark, NJ, Mar. 2003.

Abstracts:

T.L. Alvarez, K.D. Beck, A. Daftari, F. Chua, R. DeMarco, M.T. Bergen, R.J. Servatius,
"The Effect of After Image on Saccadic Eye Movements",
Proceedings of ARVO's 2003 Annual Conference, Ft. Lauderdale, FL, 2003.

To my Lola Felisa, Queen of Hearts, peace be with her.

. . .

Omnia disce, videbis postea nichil esse superfluum.
Learn everything, and you will see afterward that nothing is useless.
-Hugo of Saint Victor

ACKNOWLEDGMENT

My sincere appreciation to Dr. Tara L. Alvarez, my advisor, for constant encouragement and interest in my work. Her dedication to advisement, teaching, and learning in the field of vision research helped motivate my work and studies. Her policy seems to be *forward, always forward*. Thanks also to Dr. Stanley Reisman for advisement and teaching me the fundamentals of medical instrumentation and systems. Special thanks to Professor Michael Bergen for providing invaluable guidance, ideas, and opportunity. Many thanks to Dr. Kevin Beck and Dr. Richard Servatius for expert consultation and support.

The Stress and Motivated Behavior Institute (SMBI) at the University of Medicine and Dentistry of New Jersey (UMDNJ) and the Department of Biomedical Engineering at NJIT supported this study. All work was completed in the Vision and Neural Engineering Lab of the Department of Biomedical Engineering.

My gratitude to the staff and students of the Vision and Neural Engineering Laboratory at NJIT who provided an excellent working environment. My sincere thanks to Dr. Dennis Donahue, former Associate Dean of the Albert Dorman Honors College, for providing encouragement since I was seventeen.

Thanks to my friends and family for their continuous concern for me. Many thanks to Nita Silimkhan and Marisha N. Chinsky for love, great friendship, encouragement, and fond memories of high school.

I am very grateful to Robert M. De Marco for introducing me to Dr. Alvarez and the Veterans Affairs projects to get my research started and finished. He has always shown me love and guidance.

I am so fortunate to have a family with such solid values and steadfast care. Thanks to my parents, Jose C. and Evelyn B. Chua who raised me with unconditional love, encouragement, and responsibility. Many times they put my wants before their needs. They have always fully supported me in my choices and have always provided example lives.

Heartfelt thanks to my older brother, Jose B. Chua, for insight and help. On many occasions an offhand comment about a problem I encountered provided the spark for a solution. When my parents were preparing him for my birth, they imparted the responsibility of my welfare onto him and he seems to still take this to heart.

Warmest thanks to my younger brother, Francis, with whom I am always full of laughter. As his older sister, I was always supposed to take care of him, but now he takes care of me.

TABLE OF CONTENTS

TABLE OF CONTENTS
(continued)

Chapter **Page**

TABLE OF CONTENTS
(continued)

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES
(continued)

LIST OF FIGURES
(continued)

LIST OF FIGURES
(continued)

LIST OF FIGURES
(continued)

CHAPTER 1

INTRODUCTION

1.1 Objective

Experiments designed to study smooth pursuit require a visual stimulus that is controlled in speed and orientation. An oscilloscope was a convenient manner to produce smooth visual stimuli, but limited in ability. A visual source was sought that could display a stimulus with greater range, increased variety of colors and shapes, and greater timing accuracy.

This thesis presents the development of LabVIEW-controlled stimuli display on a computer monitor for pursuit eye movement experiments and its comparisons with oscilloscope and LED displays.

Previous studies using computer monitors for eye movement stimulus presentation have developed custom programs tailored to specific needs. In 1999, Krauzlis, Zivotofsky, and Miles investigated target selection for pursuit and saccadic eye movements using a UNIX-based real time experimentation (REX) software package created by Hays, Richmond, and Optican in 1982. This program performed stimulus presentation as well as data acquisition. Another experiment by Hodgson explored saccadic latency due to target eccentricity with custom C software written on an Apple Macintosh computer (2002).

This thesis designed and tested a LabVIEW program for presenting stimuli for smooth pursuit eye movement experiments on a computer monitor. The previously available system performed stimulus presentation and data acquisition with LabVIEW, but it had device limitations that made it difficult to investigate smooth pursuit eye movements. It involved an oscilloscope screen that was only 3.15 inches (eight centimeters) wide for stimulus display and had a slightly illuminated appearance that may have been a distracter. The newly developed system uses a sixteen-inch monitor, 12 inches (32.385 centimeters) wide for stimulus presentation. This wider screen allows for a greater range of horizontal eye movement. In addition, compared to the oscilloscope, this system allows for a greater range of colors, a wider scope of stimuli shapes, increased control of shape dimensions, and superior timing accuracy.

This thesis used engineering methods to develop an experimental apparatus suitable for pursuit eye movement experiments taking empirically determined parameters and eye movement data behaviors into consideration. This goal was achieved through the completion of several components:

1. Development of the control of eye movement stimuli on a monitor.
2. Integration of these stimuli into *Vision Research Program 2.0,* an existing program (Alvarez et al., 2003).
3. Verification of the use of a computer monitor versus light-emitting diodes (LEDs) for pursuit experiments through five-point calibration previously developed by Daftari in the *Vision Research Program 2.0* (Alvarez et al., 2003).
4. Validation of the use of a computer monitor versus oscilloscope for sinusoidal tracking of a line stimulus.

1.2 Saccadic and Smooth Pursuit Eye Movements

There are five neuronal control systems that keep the fovea on a target: saccades, smooth pursuit, vergence, vestibulo-ocular, and optokinetic eye movements. With the exception of vergence, which is disjunctive or disconjugate, the other four eye movements are conjunctive, meaning that they move the eyes in tandem towards the same direction (Alvarez, 2002). This study focuses on saccades and smooth pursuit eye movements.

Saccadic and smooth pursuit eye movements comprise a large portion of ocular activity used to visually explore the world. These eye movements are used for research in neurology, cognitive processing, reading, and weaponry design. Saccades rapidly shift the eyes to a visual target in the periphery so that the image falls directly on the fovea. Smooth pursuit gradually moves the eyes in the same direction as a target slowly moving in the visual field. The goal of pursuit is to stabilize the image of a moving object on the fovea so that the eyes can retain a high level of resolving power.

1.2.1 Physiology

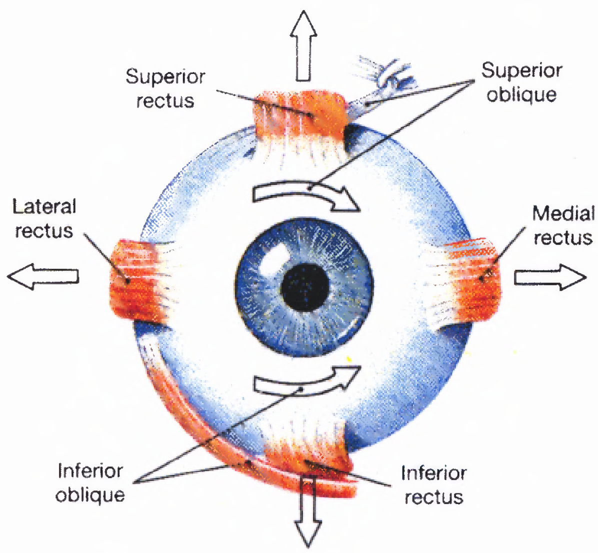

Figure 1.1 Anterior view of the right eye (Martini, 1998).

During smooth pursuit, lateral and medial recti muscles move the eyes to track a target moving along the horizontal axis, while superior and inferior recti muscles move the eyes to track a target moving along the vertical axis. Saccades use the same muscles to move the eyes to a stationary target and have significantly greater dynamics compared to smooth pursuit. While the medial rectus adducts the eye (towards the nose) and the lateral rectus abducts the eye (away from the nose), the superior rectus elevates the eye upward and the inferior rectus depresses the eye downward. The inferior division of the oculomotor nerve (Cranial Nerve III) innervates the medial-, superior-, and inferior recti while the abducent nerve (Cranial Nerve VI) innervates lateral recti.

For a horizontal eye movement, Cranial Nerve VI directly innervates the lateral muscles as Cranial Nerve III innervates the contralateral oculomotor nucleus, which innervates the medial rectus. This activates both muscles, resulting in conjugate eye movement (Buttner et al., 1992).

1.2.2 Neuroanatomy

A saccade is a quick movement from one location to another beginning in the paramedian pontine reticular formation (PPRF) (Alvarez, 2002). PPRF burst neurons generate a phasic movement command proportional to velocity, and then tonic neurons in the prepositus hypoglossi (PPH) convert the phasic command to a tonic command-converting velocity to position. Motorneurons in the brain stem combine phasic (pulse) and tonic (step) commands, contracting the oculomotor muscles, which quickly rotates the eyes and keeps them there against elastic forces. The cerebral cortex controls the cognitive aspect of saccades, deciding when and where to make a saccade. The integration of cognitive and motor parts is completed at the superior colliculus.

Pursuit is a response to the motion of the target's image across the retina. A popular view supported by Lisberger, Morris, and Tychsen states that the brain dictates smooth pursuit via a negative feedback control system (1987). The purpose of this system is to minimize retinal slip of images from small target objects. Figure 1.2, a top-level model, illustrates a negative feedback control system where image motion provides the main command to the efferent pathways for pursuit.

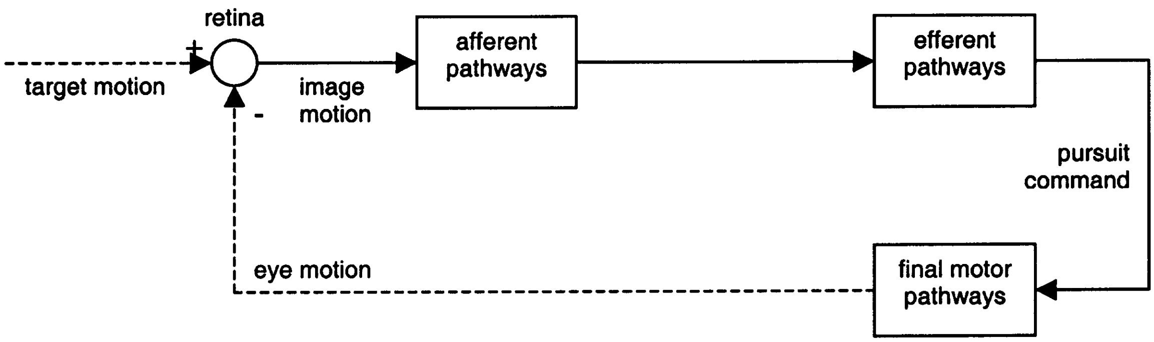

Figure 1.2 An example model of the pursuit system (Lisberger et al., 1987)

Neural control of smooth pursuit eye movements begins with input received from motion sensitive neurons in the middle temporal (MT) or V5 and medial superior temporal (MST) areas of the cerebral cortex. These areas are essential for the initiation and accurate guidance of smooth pursuit. MT and MST neurons either directly transmit signals to the dorsolateral pontine nucleus or indirectly send signals through the frontal pursuit region within the frontal eye fields (FEF) before reaching the cerebral cortex. The cerebral cortex processes the information about motion and sends this to the paramedian pontine reticular formation (PPRF), which generates a motor command (Leigh et al., 1991).

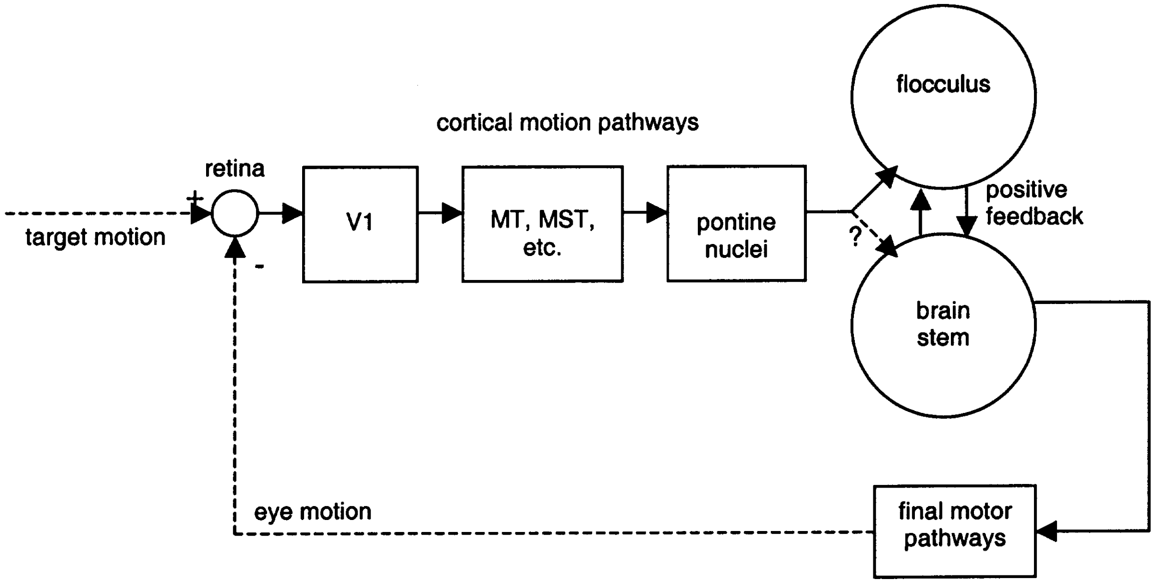

Figure 1.3 A computer model that simulates pursuit at one millisecond resolution. Cortical motion pathways relate to afferent limb of pursuit. Pontine nuclei correspond to the sensory motor interface, and the positive feedback relates to efferent pathways (Lisberger et al., 1987).

1.2.3 Characteristics and Parameters

The saccadic oculomotor system can produce saccadic eye movements that are either voluntary or involuntary depending on the size. Small saccades that accompany fixation cannot be produced voluntarily, while larger saccades in which direction of fixation is changed, may be either voluntary or involuntary (Yarbus, 1967).

Saccades can have speeds up to 900°/sec. The minimum amount of eye movement for a saccade is one minute of arc while an ideal saccade covers ten to fifteen minutes of arc per second (Yarbus, 1967). According to Yarbus, saccades have two characteristic features:

1. A nearly identical eye movement measurement of both eyes;
2. High velocity- as the duration of a saccade is measured in hundredths of a second.

Amplitudes of saccades rarely exceed 20° because movements that would require greater than 20° are typically accompanied with head motion. For angles less than 1°, the durations of saccades are 0.01- 0.02 seconds and for angles of about 20°, durations may reach 0.06-0.07 seconds.

The pursuit oculomotor system has voluntary and involuntary aspects. Yarbus observed that pursuit could voluntarily be started or stopped if a moving object is present in the field of vision (1967). However, without special training, an observer cannot voluntarily interfere with the actual process of pursuit and change its speed intentionally, making it greater or lesser than the speed of the moving target. A second involuntarily characteristic of pursuit eye movements is their smoothness (Yarbus, 1967). This was further confirmed by a study that found that subjects were widely and consistently able to make smooth eye movements while tracking a real target, but unable to make smooth eye movements while tracking an imaginary target (Figure 1.4), (Churcher et al., 1971). Instead, staircases of small saccades were produced. Furthermore, in pursuing an imaginary target, during intersaccadic intervals which typically last about 200 milliseconds each, the eyes are stationary, showing that a visual stimulus is necessary to evoke pursuit (Lisberger, 1987). Additionally, the ability of the eyes to develop smooth movements following an oscillating target almost exactly suggests high *automatic* computation ability by the visual system for controlling eye movements.

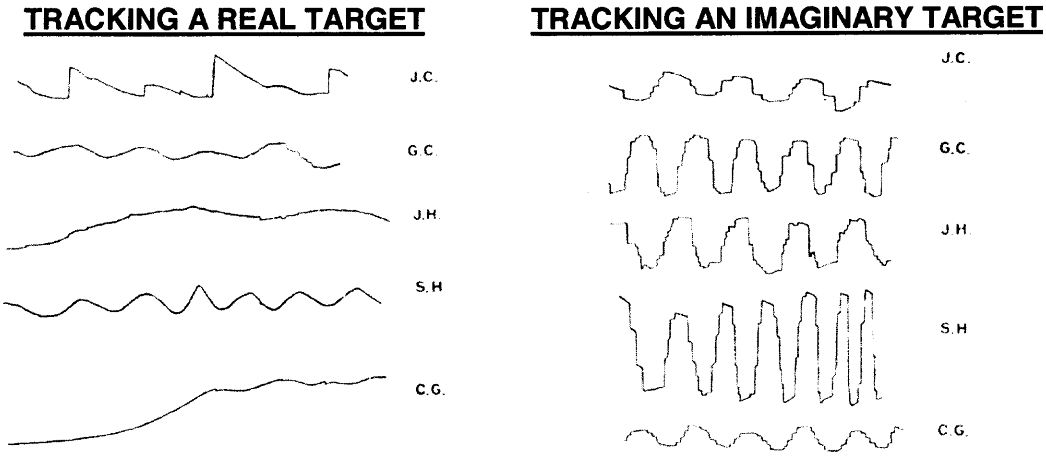

Figure 1.4 The left shows tracings of EOG recordings of subjects tracking an afterimage. 20° of horizontal eye movement were made, shown for 1-5 seconds. The image on the right shows tracings of EOG recordings of subjects trying to track an imaginary pendulum. (Churcher et al., 1971).

Smooth pursuit eye movements are generally slow and smooth. They almost exactly match target velocity when the target speed is less than 100 – 200 degrees per second (Yarbus, 1967). Pursuit can still occur with eye velocities as high as 180 degrees/second but with saccades and inaccurate tracking (Lisberger et al., 1981).

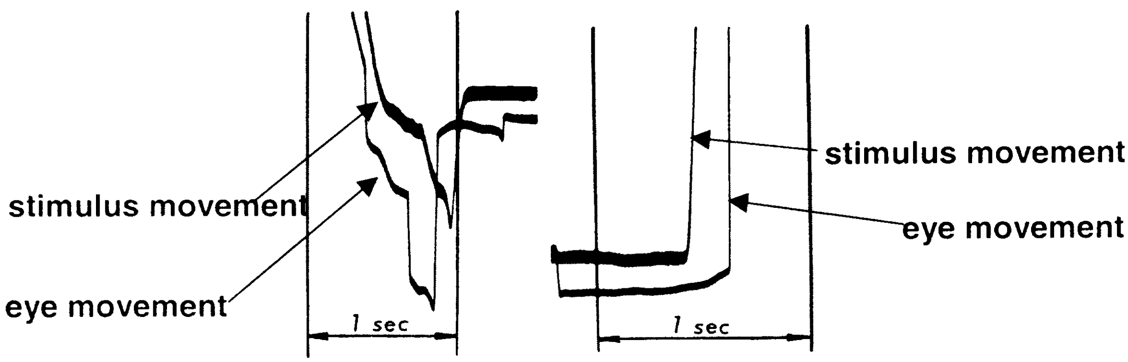

Figure 1.5 Recordings of eye movements (thinner line) in response to an object movement (thicker line). This illustrates the delay of eye movements during smooth pursuit initiation (Yarbus, 1967).

Pursuit latency is the amount of time that a moving target must be present in the field of vision before smooth pursuit begins. Most researchers including Yarbus have determined pursuit latencies of 80 to 130 milliseconds (1967), while Lisberger and

Westbrook found that pursuit latency could be as short as 60 milliseconds for a small target (1985).

Stark determined that the pursuit system is capable of prediction (1962). This is due to motion sensitive neurons in the MT and MST afferent areas of the cerebral cortex. When activated, MST neurons remain firing while MT neurons decrease firing as a moving target slows down or disappears, allowing for prediction (Alvarez, 2002). Since prediction causes increased pursuit accuracy, a target with periodic movement will produce smoother and more accurate eye movements than an unpredictable target (Lisberger, 1987).

To attain smooth pursuit, the frequency of target motion must not exceed 1 Hertz (Hz). A target oscillating at this frequency stimulates mostly smooth eye movements accompanied by some corrective saccades (Figure 1.6a). A lower oscillation frequency of about 0.33 Hz results in even smoother pursuit responses (Figure 1.6b). A frequency of 3 Hz results in eye movements with considerably less amplitude compared to the amplitude of the oscillating target (Figure 1.6c), while a target oscillating at 4 Hz results in a complete failure of pursuit (Figure 1.6d). Thus, smooth pursuit is most accurate when the frequency of target motion is less than 1 Hz. With greater frequency, smooth eye movements are unable to maintain the target fixation, where tracking is interrupted with saccades (Lisberger, 1987).

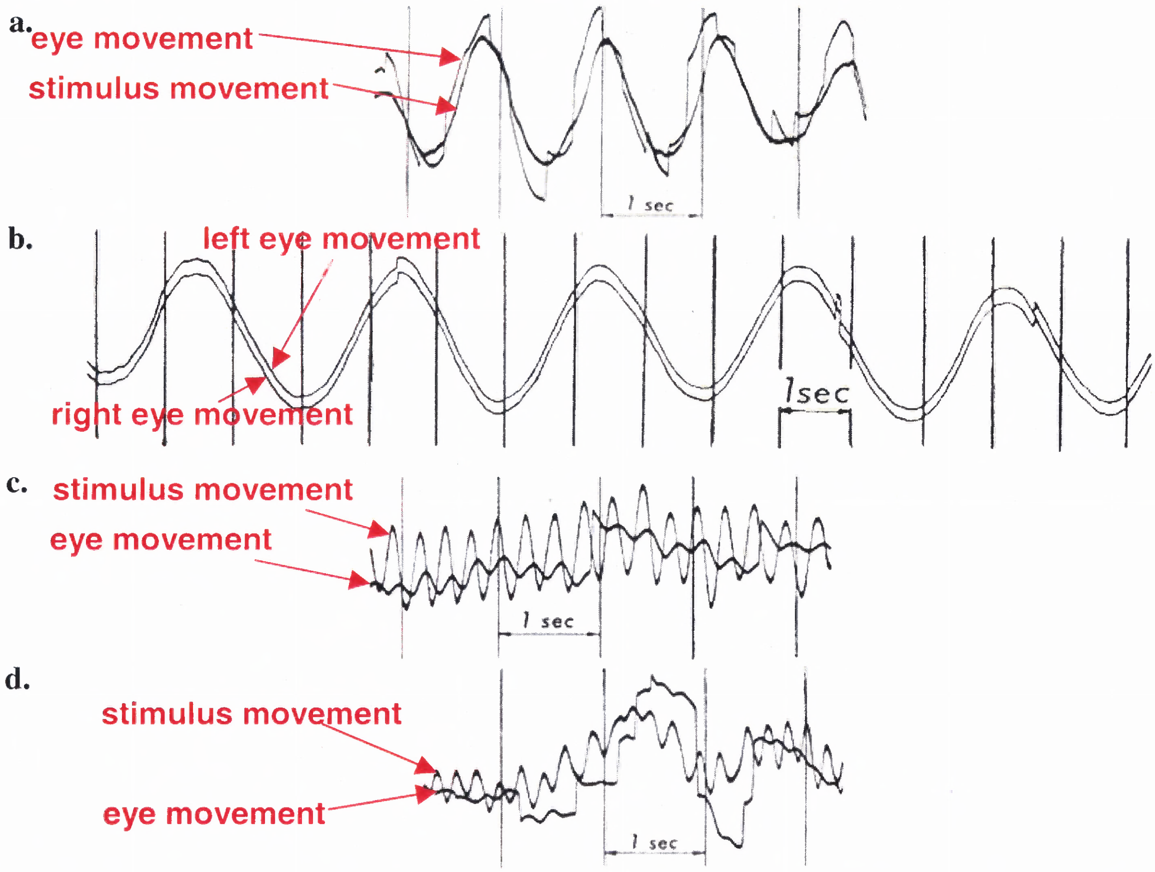

Figure 1.6 Simultaneous records of eye movements and object movements in a, c, and d. Object movement in each graph appears smoother than eye movement. The top graph **(a)** shows somewhat accurate pursuit. Graph **(b)** demonstrates very accurate and smooth pursuit with both eyes. Graph **(c)** shows a shift in phase (as a result of delay of the eye) and diminished amplitude of eye oscillations compared to unpredictable object movement. Graph **(d)** illustrates a total failure of pursuit for unpredictable target movement. (Yarbus, 1967).

CHAPTER 2

INSTRUMENTATION METHODOLOGY

The purpose of this thesis was to develop increased capabilities of stimulus types to evoke various eye movements. This goal was attained by developing a program with the programming language LabVIEW by National Instruments that presents stimuli appropriate for smooth pursuit eye movements on a computer monitor. The program was integrated into an existing program, *Vision Research Program 2.0,* for eye movement experiments which controlled the display of stimuli with oscilloscopes, light-emitting diodes (LEDs), and photic stimuli while acquiring eye movement data (Alvarez et al., 2003).

Existing equipment of the Vision and Neural Engineering Lab of NJIT included five LEDs arranged for saccade experiments, two oscilloscopes configured for vergence experiments, a Bayonet Neill-Concelman (BNC) adapter, the Skalar Model 6500 infrared limbus eye tracking system, and a Dell Optiplex GX240 Pentium IV, 1.70 GigaHertz (GHz) computer with 256 MB of RAM operating with Microsoft Windows XP Professional 2002. This computer contained a data acquisition (DAQ) board, model 6024e series from National Instruments. In addition to these devices, available for this experiment were three computer monitors and a three-output Matrox Parhelia™ 128MB videocard for the operating computer.

An oscilloscope screen may be used for visual smooth pursuit stimulus presentation of a single monochromatic line of fixed height, but only for a maximum of ten degrees of horizontal movement per eye from midline at roughly nine inches from the subject. Analog oscilloscopes also have a tendency to drift and may exhibit low timing accuracy. Their screens appear to be slightly illuminated during stimulus presentation, which may be a distraction from the stimulus. While light-emitting diodes could be placed in a greater range in space, they are discrete units incapable of animation.

2.1 Visual Displays

Two of the main purposes of this thesis were to verify the use of a computer monitor in pursuit eye movement experiments by testing them against LEDs through five-point calibration and to replace an oscilloscope for pursuit eye movement studies.

2.1.1 Light-Emitting Diodes

An LED contains a p-n junction, which emits light due to a recombination of charge carriers. As they generally last long lifetimes they exhibit robust and efficient characteristics. Green-colored diodes containing galliumphosphide are the second least expensive compared to red-colored diodes.

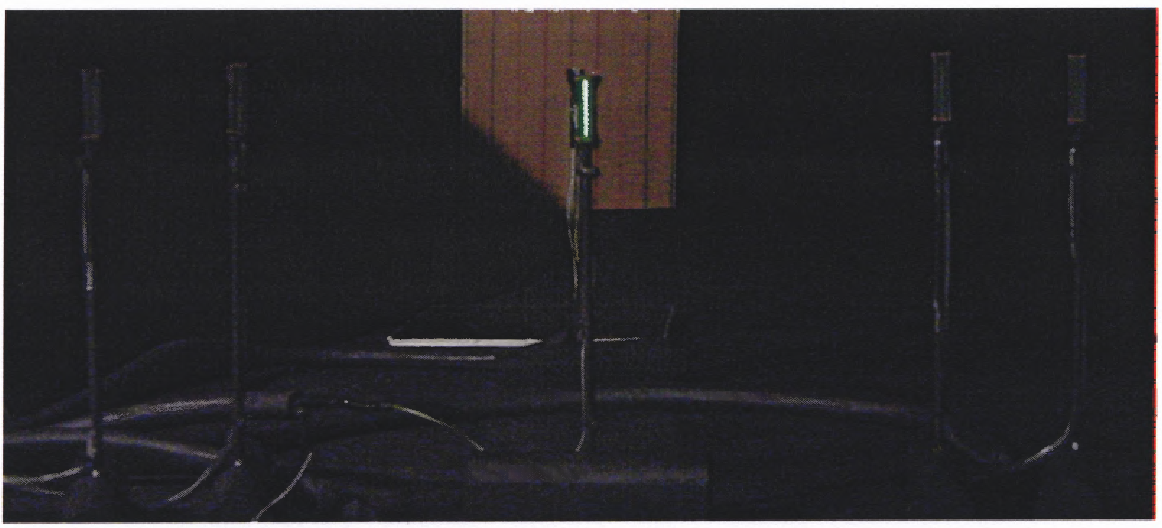

Figure 2.1 Five LEDs arranged in a horopter for five point calibration of an eye movement monitor.

Five green, vertical bar LEDs at ±20, ±15, and 0 degrees placed in a horizontal horopter in a subject's visual field currently serve as the five-point calibration stimuli for an eye movement tracker in saccadic eye movement experiments. Since saccades and pursuit can both move the eyes in tandem in the horizontal axis from -20 to +20 degrees, the LED set-up served as a suitable control to compare with targets on a computer monitor via five-point calibration. Though LEDs can be placed anywhere in free space, they have widths which may create fixations or eye movements fractions of a degree off from the actual desired target position. This requires the LED to be masked as seen in Fig 2.1 to reduce these errors.

2.1.2 Oscilloscopes

An oscilloscope is a device that graphically displays waveforms of voltage versus time. Since oscilloscopes emit light stimuli, they are suitable for most eye movement experiments in the dark. Oscilloscopes are often used in pairs in vergence eye movement experiments as each oscilloscope displays a line stimulus towards two mirrors, 45 degrees to a subject's line of sight. The subject can visually fuse this pair of lines into a single line. This configuration is referred to as a haploscope (Figure 2.2).

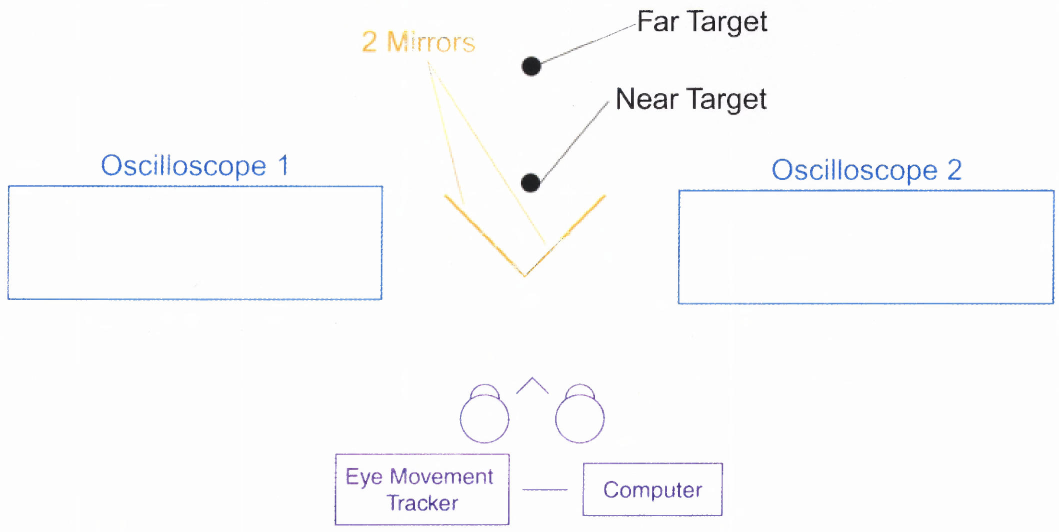

Figure 2.2 A haploscope arrangement.

While oscilloscopes are appropriate for some eye movement experiments, they exhibit limitations for smooth pursuit. The Vision and Neural Engineering Laboratory owns a BK Precision® 2120B Dual Trace Oscilloscope which has an accuracy of ±3% (BK Precision® Corporation, 2000). This analog oscilloscope is capable of near real time display but may exhibit oscillator drift. On the other hand, digital oscilloscopes can display more consistent oscillations but may have display flicker, making them poor candidates for real time display. Generally, oscilloscopes have small display screens of about 80 square centimeters (about 12 square inches), and low sophistication of monochrome graphics.

In contrast, computer monitors have wider display screens, the ability to display many colors and more complex graphics, are more consistent in display, and have some flicker-free capability. Though the planar quality of flat screen monitors causes some loss of arc in eye movement calculations, these losses of arc can be determined.

2.1.3 Monitors

A relatively inexpensive, high-performance flat screen monitor was necessary for the experimental set-up as a visual display. Known for its products in visual display, ViewSonic produced the E70fb 17-inch (16-inch viewable) (12 inches or 32.4 cm wide) color flat screen cathode ray tube (CRT) monitor. The monitor has a 0.21-millimeter horizontal and a 0.25-millimeter diagonal dot pitch and best performs at a resolution of 1024 x 768 pixels. Its flat screen allows for reduced image distortion. This monitor complies with MPR-II standards for safe radiation levels. (ViewSonic Corporation, 2002).

Oscilloscopes can display only one or two colors while computer monitors can display up to 32 bits (over four billion) of colors depending on the video card. A computer monitor and videocard are comparable in cost to analog oscilloscopes with CRT displays but less than one-tenth the cost of digital oscilloscopes with LCD displays.

2.1.4 Videocard

A videocard capable of real time multimonitor display was a key device for the experimental apparatus. Initially purchased was the Matrox G200 Multi-Monitor Series™ (MMS) Peripheral Component Interconnect (PCI) card, which was capable of four-monitor output but was discovered to be unable to output close to or in real time in LabVIEW. The later purchased Matrox Parhelia™ card could output to only three monitors, but was much closer to real time display. It had 128 Megabytes of memory, and Accelerated Graphics Port (AGP) Bus designed by Intel to provide a direct connection between the videocard and the main system random access memory (RAM). The Matrox G200 card only had 32 Megabytes of RAM. This PCI card did not contain a bus exactly, but a bridge allowing asynchronous access between the central processing unit (CPU) and slower peripherals. The importance of increase in memory from the G200 MMS card to the Parhelia™ card is that it allowed for additional buffering.

2.2 Peripheral Devices

2.2.1 Eye Movement Tracker

The quality of data from vision experiments depends on accurate eye movement tracking. A limbus tracker and a corneal reflection tracker both provide non-invasive methods for monitoring eye movements. A limbus tracker detects the boundary of the iris and sclera on the nasal and temporal sides of the eye through the use of a differential infrared system at a wavelength of 950nm. A corneal reflection tracker detects the displacement of the center of the cornea's curve due to rotation. A limbus tracker permits either horizontal or vertical eye movement tracking at one time, but has a frequency response much faster than corneal reflection. While corneal reflection allows for simultaneous horizontal and vertical eye tracking, they are more costly than limbus trackers. Also, limbus trackers are capable of either analog or digital high-resolution output but corneal reflection trackers output low-resolution digital output (Young et al., 1975).

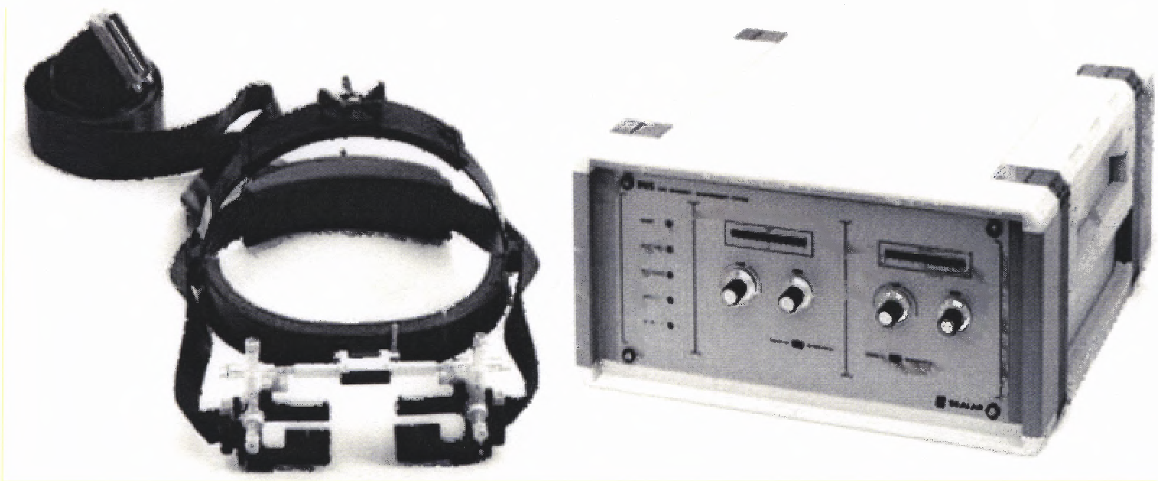

Figure 2.3 The Skalar Iris Limbus Tracker model 6500 (Cambridge Research Systems, Inc., 1999).

The Vision and Neural Engineering Laboratory is equipped with The Skalar IRIS Limbus Tracker model 6500. It has a resolution of two minutes of arc and a linearity of $\pm$25 degrees (Cambridge Research Systems, Inc., 1999). This device has an eyepiece for each eye containing nine light-emitting diodes placed above the exposed portion of the eye and nine photodetectors below. For proper operation of the limbus tracker, a white line on the bottom of the eyepiece must be aligned with the center of the pupil. Light emitted from the top part of the eyepiece reflects off the sclera more than the iris, creating a difference for the detection of eye position. The black box accompanying the limbus tracker has a pair of knobs for both left eye and right eye, which adjust gain and offset.

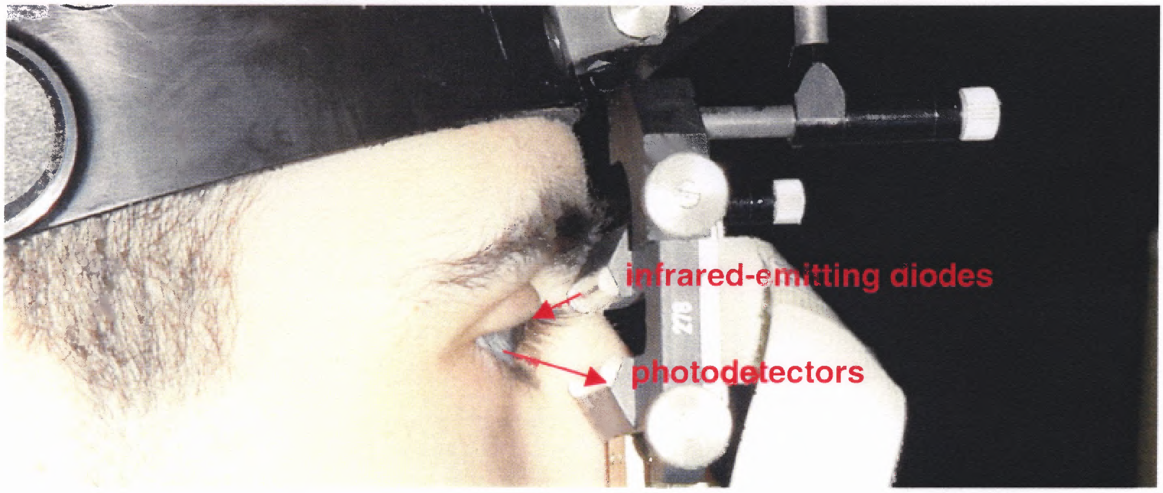

Figure 2.4 The Skalar Limbus Tracker on a subject. Infrared-emitting diodes shine light onto the eye on the nasal and temporal sides as photodetectors detect the light reflected.

In accordance to ASNSI Z136 Safety for lasers specifications and OSHA specifications, infrared can be shined onto eyes for two hours at 10 milliWatts (mW) per square centimeter (cm) (Alvarez, 2002). The Skalar IRIS Limbus Tracker emits 0.8 mW/cm^2 (Cambridge Research Systems, Inc., 1999).

2.2.2 Data Acquisition Board

The operator computer in the Vision and Neural Engineering Laboratory is outfitted with a Data Acquisition (DAQ) board, model 6024e, from National Instruments, which records incoming analog signals as voltage values and outputs digital signals to the oscilloscope, and LEDs. This DAQ card has 8 inputs or 8 outputs that can read or write 5 volts as well as two 12-bit analog outputs. This card fully integrates with National Instruments software such as LabVIEW.

2.2.3 Bayonet Neill-Concelman Adapter

The Bayonet Neill-Concelman (BNC) is a type of radio frequency connector used for terminating a coaxial cable. A coaxial cable is designed to carry a high-frequency signal and is insulated to minimize interference with or encounter interference from external electromagnetic fields.

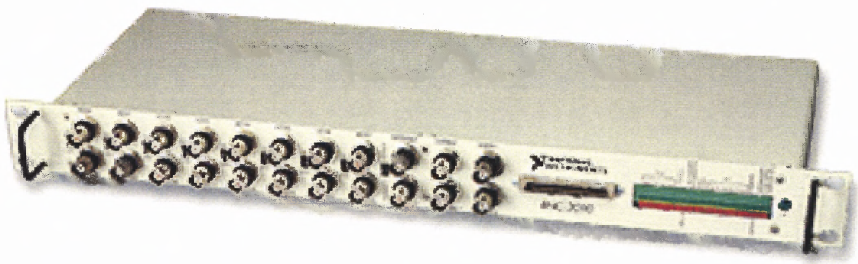

Figure 2.5 The BNC 2090 adapter (National Instruments Corporation, 2003).

The BNC-2090 is a shielded, rack-mounted adapter in the Vision and Neural Engineering Lab. It has twenty-two BNC connectors and twenty-eight spring terminals for connections to analog, digital, trigger, and counter signals. This adapter can directly connect to *E series* DAQ boards (National Instruments Corporation, 2003).

2.2.3 Trigger

All eye movement experiments in the Vision and Neural Engineering Laboratory are under complete subject control through the use of a trigger. Once a subject feels he or she is ready to begin, he or she can initiate an experiment by pressing a trigger button. To avoid loss of signal during typical eye movement experiments, subjects frequently need to keep their eyes open for three to five seconds at a time, throughout which eye movements in response to stimuli are recorded. Smooth pursuit experiments may last longer so that subjects may feel the need to blink, but nonetheless, a simple but responsive trigger under complete subject control, is used to communicate that they are ready to keep their eyes open for an experimental trial. When the trigger button is pressed, a random delay between 0.5 to 2 seconds occurs before stimulus presentation to avoid prediction of stimulus onset.

During the development of this study, ongoing experiments required the use of additional digital bits so that a trigger originally using a digital bit was moved and configured to an analog *TRIG1* (channel 2) on the BNC 2090 through LabVIEW, a program from National Instruments (See Appendix A).

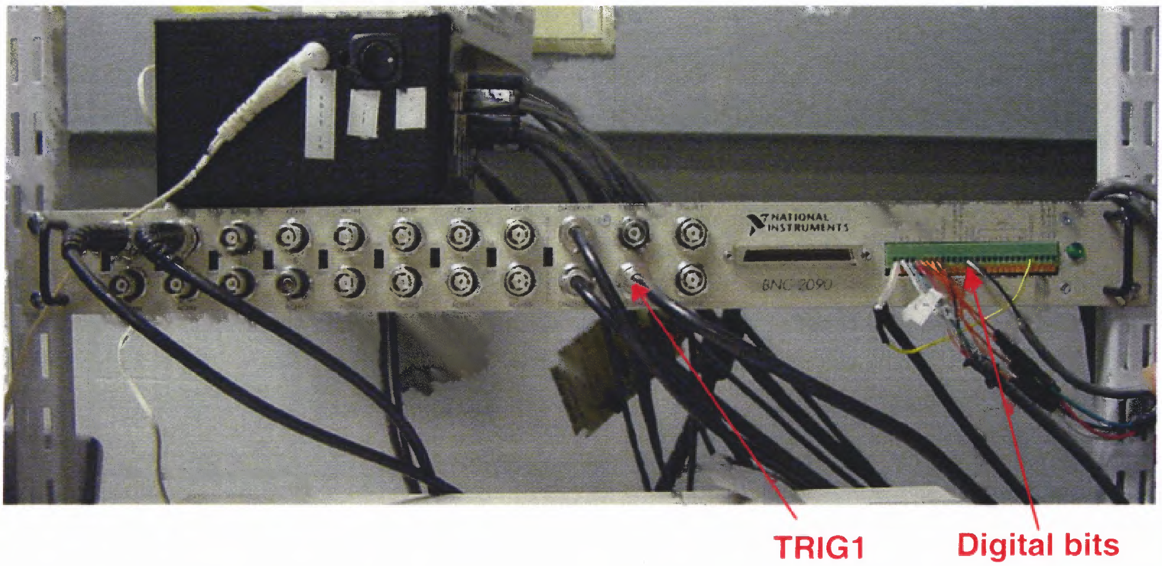

Figure 2.6 The BNC 2090 Adapter in the Vision and Neural Engineering Lab. Analog connectors are on the left while digital connectors are on the right.

2.3 Programming Languages

Smooth pursuit eye movement experiments involve real time control of stimuli as well as data acquisition. Lab View's Picture Control Toolkit was strongly considered in the development of visual stimuli since it could be directly integrated into the Vision Research Program 2.0 which controlled visual stimuli such as LEDs, photic stimulators, and oscilloscopes while acquiring data through an eye movement tracker and trigger. A robust modifiable data analysis program that already existed was written with MatLAB®, which was the central reason for using it for data analysis (Semmlow, 1995; Alvarez 1998).

2.3.1 LabVIEW

LabVIEW Version 6i, an industry standard, can be programmed for custom functionality. Picture Control Toolkit, a graphical control suite available with and since the release of LabVIEW 5.1, is capable of displaying static and animated lines, shapes, and images in real time although it has limitations. Ideally, this study desired a visual stimulus of a vertical line oscillating on a computer screen at a wide range of frequencies. Due to LabVIEW's timer and delay resolution of one millisecond at optimal computer performance, it was incapable of displaying a moving target at certain frequencies which required resolutions less than one millisecond. Also, flicker was unavoidable at frequencies greater than 0.33 Hz for a smoothly moving sine wave stimulus and 0.7 Hz for a smoothly moving ramp stimulus due to videocard graphics limitations. Therefore, a stimulus set was created that worked optimally at a sinewave target movement frequency of 0.33 Hz or less and at a ramp target movement frequency of 0.7 Hz or less, which are appropriate stimuli movements for smooth pursuit experiments.

2.3.2 MatLAB®

This study needed a program that would help reduce data analysis time. MatLAB® 6.1 (Matrix Laboratory) is a technical computing program for high performance computing and visualization. Its base data element is a matrix that does not require dimensioning, allowing time-efficient numeric problem solving in a short amount of time. The open architecture of MatLAB® allows the user to create algorithms and custom tools

(MathWorks, Inc., 2003). It has a *ginput* command, which first permits the operator to click on a particular point in a graph, and returns the cross hair (point that the user clicked on) x- and y-axis values. The *Vision Data Analysis Program 2.0,* written in MatLAB®, was used to analyze data from experiments in this thesis (Semmlow, 1995; Alvarez 1998).

2.4 Stimuli Development

Control of an appropriate set of stimuli for smooth pursuit eye movement experiments was developed using Picture Control Toolkit (PCT), a graphical control suite accompanying LabVIEW Version 6i. The Vision Research Program 2.0, used in the Vision and Neural Engineering Lab for vergence and saccade experiments, first calibrates an eye movement monitor, and then performs stimuli presentation and data acquisition for twelve types of stimuli. This thesis modified the five-point calibration for a monitor display and developed four additional types of stimuli, also to be used with the monitor display: square wave, ramp, sine wave, and an oscillating circle. Key goals in developing these stimuli were smoothness of target movement and timing accuracy.

Drawing a single vertical line is the basis for these eye movement stimuli. The following illustrates how a line is drawn in LabVIEW with Picture Control Toolkit.

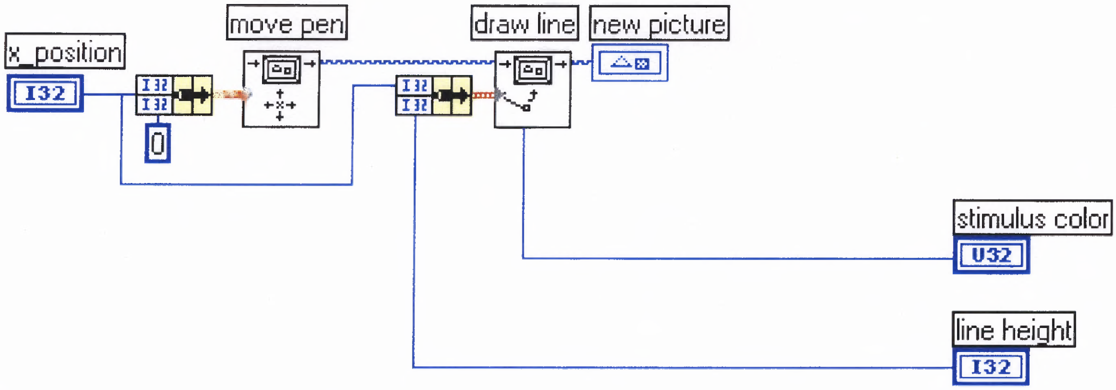

Figure 2.7 The LabVIEW diagram of the process of displaying a vertical line to a picture indicator the control (front) panel.

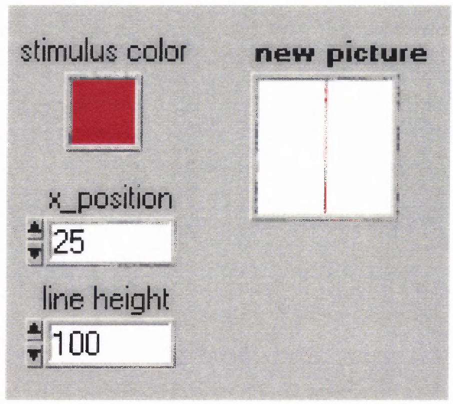

Figure 2.8 The front panel of the controls taken into account when a line is drawn in a picture indicator, *new picture*, in LabVIEW.

The control called *x_position* dictates where to move the pen and draw the line along the horizontal axis of the computer screen. *Line height* and *stimulus color* are operator-defined. The *move pen.vi* relocates the pen to the specified x- and y-values. Then *draw line.vi draws* a vertical line starting from the x-position to the y-position specified by *line height*. This virtual instrument (VI) draws a line of stimulus color in a picture indicator *new picture as* shown in Figure 2.8.

Hardware timing, rather than software timing, was developed for all stimuli including the ramp, sine wave, and oscillating circle, all which control the movement and position of a line or shape through a for-loop. This loop iterated 250 times per second, which was the slowest output rate at which the stimulus appeared flicker-free. A greater rate contributed to display delay. Hardware timing was tested to be unnecessary for the square wave since it required less computer resources due to a decrease in screen refresh rate and was determined to be accurate to one millisecond resolution with a software timer. The other stimuli required hardware timing since they were more resource dependent due to rapid graphical movement.

With a software timer, stimuli timing would be in error by as much as ± 30 milliseconds per period. Hardware timing reduced this to between zero and six milliseconds in error per period.

While hardware timing resolved the majority of accuracy issues, smooth target movement, void of flickering, was also a central objective. Three methods were attempted then tested to display a moving line on the computer monitor. Using a sequence of frames of images was one way of creating the appearance of smooth movement. While this approach allowed for ease in displaying animations of complex objects, the amount of computer memory allocated for constantly redrawing the entire field was excessive for the purposes of this thesis. This also increased inaccuracy in timing causing delays and therefore flicker.

Another method thought to produce smooth target movement, in the case of a vertical line target, was to repeatedly: move the "pen", draw the line, erase the entire picture by overdrawing the whole area with a rectangle the same color as the background, then move the pen, then draw another line. This method only worked well for target oscillation frequencies much lower than those desired for this thesis. At greater frequencies, erasing the entire picture caused flickering and time delays.

The technique that was the most efficient in generating smooth and time-accurate target movement was to repeatedly:

1. Move the pen;
2. Draw the stimulus line;
3. "Erase" the stimulus line by drawing another line of the same color as the background over it while drawing a new stimulus line in another position.

This method eliminated delays associated with erasing the entire picture field every time a new stimulus line was drawn.

During an experimental trial, Vision Research Program 2.0 displayed eye movement recordings on the operator's computer monitor every ten milliseconds. While this provided more real time information to the operator, it caused great timing inaccuracy in stimulus display on the subject-viewable monitor. To eliminate timing inaccuracy, eye movement recordings were programmed to display at the end of each experimental trial for the modified Vision Research Program 2.0, now *Vision Research Program 3.0.*

2.4.1 Draw Sub-Virtual Instrument

A sub-program (sub-virtual instrument or sub-VI) called *draw.vi* was developed as part of this thesis, containing frequently used sets of functions, which write to the picture indicator on its front panel. The front panel for this sub-VI is completely black and only used for stimulus display. Draw.vi opens its front panel in a new window separate from the main program, Vision Research Program 3.0. This sub-VI was enabled to open and close synchronously with Vision Research Program 3.0 and run when it was called. The front panel picture indicator was initially set by hand to display on a second monitor where subjects viewed the stimulus. Draw.vi was configured for highest time critical priority and auto-handling of menu selections when opened or run. This prevents the operator from changing any settings while the sub-VI was opened or run through the Vision Research Program 3.0.

Draw.vi contains three cases labeled "0", "1", and "16". Case 0 controls the display and erasure of a single vertical line and is the default case. Erasure of the line involves drawing a black line of the same height over the stimulus. Case 16 is labeled as such to correspond with its stimulus number in the Vision Research Program 3.0. This case controls the display of a circle and its erasure by a black rectangle. A rectangle was chosen as an eraser rather than a circle since it had simpler edges for faster computer performance. Case 1 is responsible for the erasure of the entire picture indicator by drawing a black rectangle in the entire area.

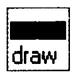

Figure 2.9 Draw.vi icon. This icon appears several times within this section.

Draw.vi has seven possible inputs and one output. Its inputs include: stimulus type, line width, shape width, shape height, stimulus color, x_position, and x_position_erase (overdraw location). The last two inputs control the position of the stimulus line and the eraser line. This sub-VI's output is displayed on the picture indicator.

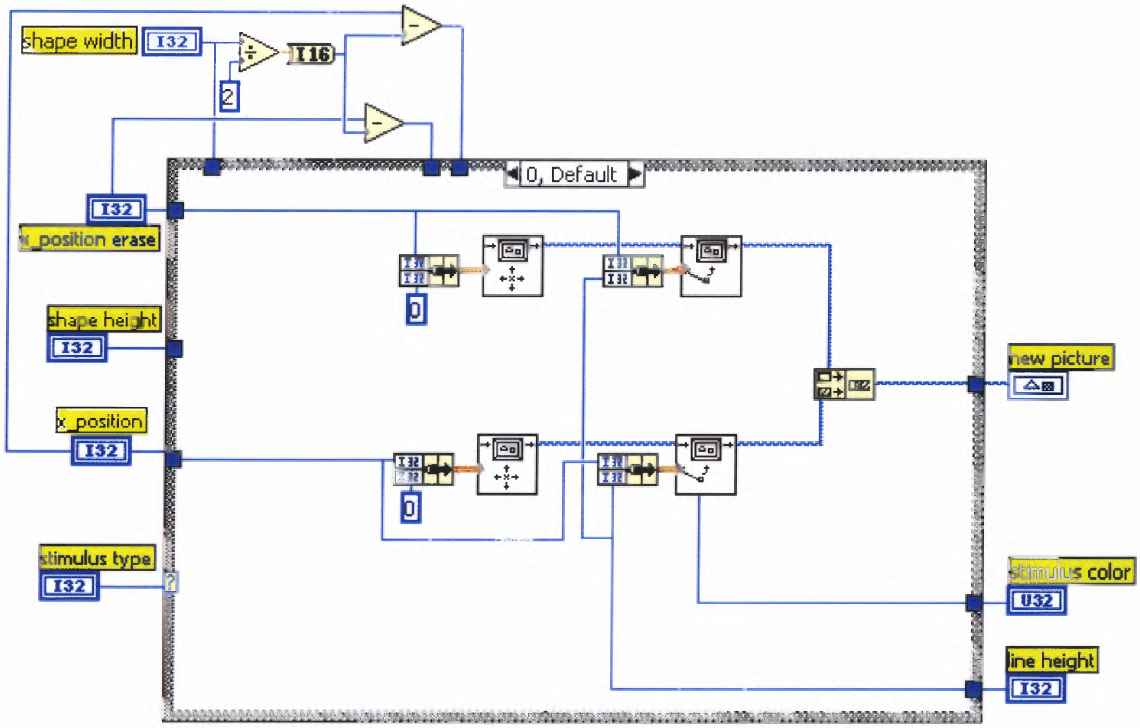

Figure 2.10 The LabVIEW diagram of the "0" default case of draw.vi in which a line is drawn and erased.

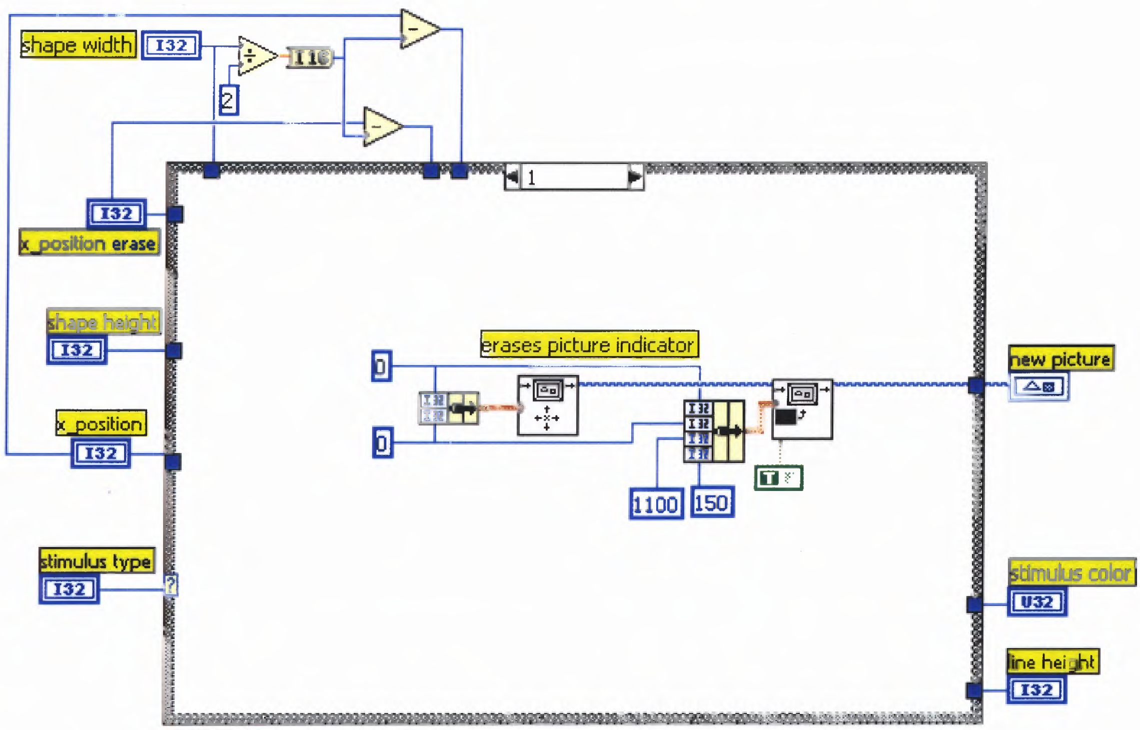

Figure 2.11 A diagram of the "1" case of draw.vi in which the entire picture indicator is erased.

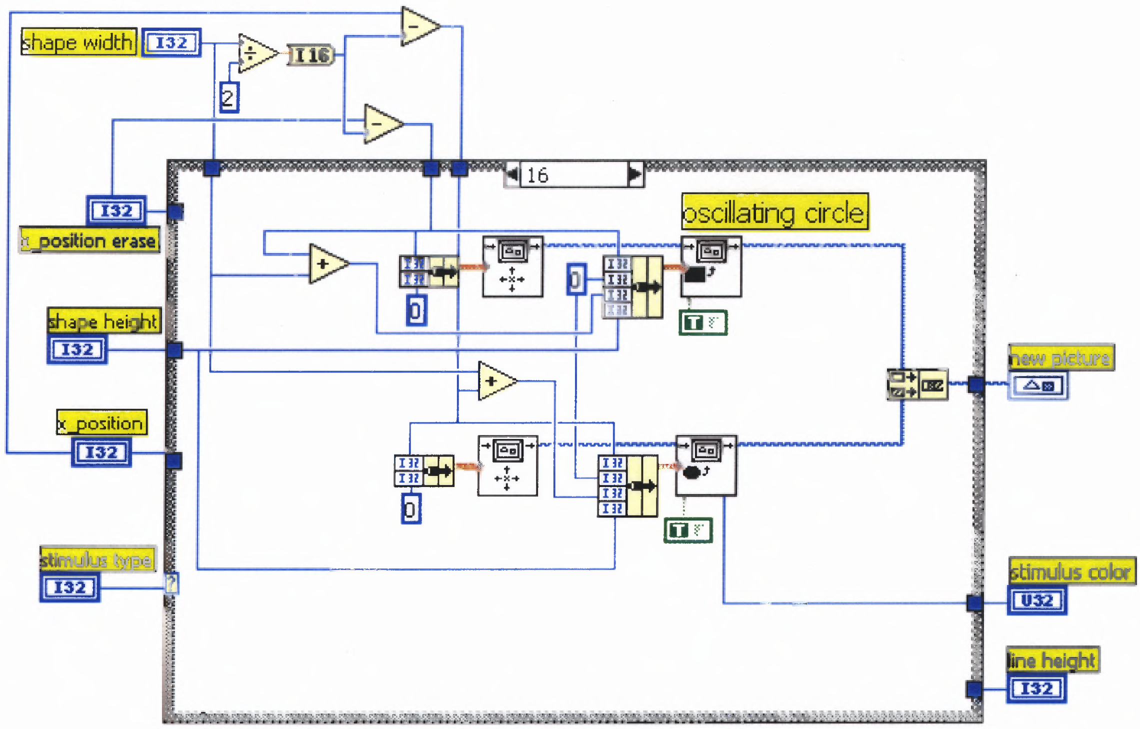

Figure 2.12 A diagram of the "16" case of draw.vi in which a circle is drawn then erased by a black rectangle.

2.4.2 Calibration

Five-point calibration of the eye movement monitor in the Vision Research Program 2.0 successively presented a subject with fixed LED targets at 0°, ±15°, and ±20° in the horizontal plane while acquiring eye position data at 1000 Hz for five seconds per target. A 0° target at midline was displayed before each experimental trial. When the subject was ready, he or she pressed a trigger and was presented with a target stimulus. As he or she fixated upon it for five seconds, data was recorded. The last 4.5 seconds of response data was averaged.

To calibrate the eye movement tracker for pursuit experiments, five identical, vertical line targets at positions -20, -15, 0, +15, and +20 degrees are programmed to display successively on the computer screen the subject views. The zero degree is the initial target position, which is along the subject's midline. Positive stimuli are toward the right visual field while negative stimuli are toward the left visual field.

One feature that makes the monitor more flexible than LEDs in calibration was the adjustment for inter-pupillary distance (IPD) in stimulus display target placement (See Appendix B.2). Due to the flat nature of the screen, if inter-pupillary distance (IPD) is 6 centimeters (cm), the amount of error per eye is between ±2.8 percent as follows (Calculations are described in Appendix B.3):

Table 2.1 Amount of Error Per Eye Due to a Flat Screen Monitor at 40 Centimeters from the Subject

Target	Left Eye	Right Eye
-20º	-2.05%	+2.95%
-15º	-1.4%	+2.4%
0º	0 %	0%
+15º	-2.4%	+1.4%
+20º	-2.95%	-2.05%

In binocular vision, a *horopter* is a theoretical shape determined by the point of fixation and the centers of both eyes. Fixation on any point on this horopter within the field of binocular vision causes corresponding retinal points for zero horizontal retinal disparity. Figure 2.12 illustrates an example of a horopter for a target, a specific distance from the eyes. *Panum's fusional area* is the region where an object can be successfully fused. Areas beyond this region may cause disparity while those before this region may be unfusable (Churchland et al., 1999).

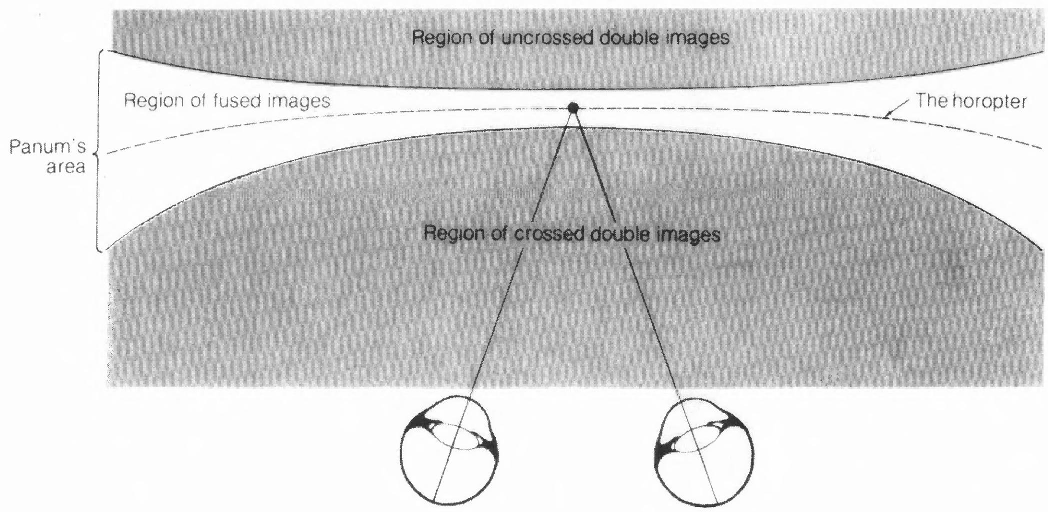

Figure 2.13 The horopter and Panum's fusional area for a target at a fixational distance. Objects closer to the subject are considered *crossed* and those farther are *uncrossed* (Coren and Ward, 1989).

When fixating on calibration targets, varying IPDs from subject to subject can cause disparity. Thus, IPD was programmed to be operator-controllable within the monitor display program. If desired, the operator can enter the IPD of a subject. Otherwise the program defaults to 6 cm, which is a widely accepted average. If the subject has an IPD of 5 cm or 7 cm, and the program is left to default at 6 cm, at extreme assessable targets of $\pm 20°$, amounts of error are 1.7% to 2.25%, and 2.2% to 3.3% respectively.

The development of five-point calibration using the computer monitor for stimulus display involved two sub-VIs: *draw.vi* and *degrees to pixels.vi*. Degrees to pixels.vi, which converts target position in degrees to that in pixels is further described in Appendix B.2. Calibration first erases the picture indicator then presents the subject with a vertical line of operator-specified height and color at 0 degrees (midline) until he or she presses the trigger button.

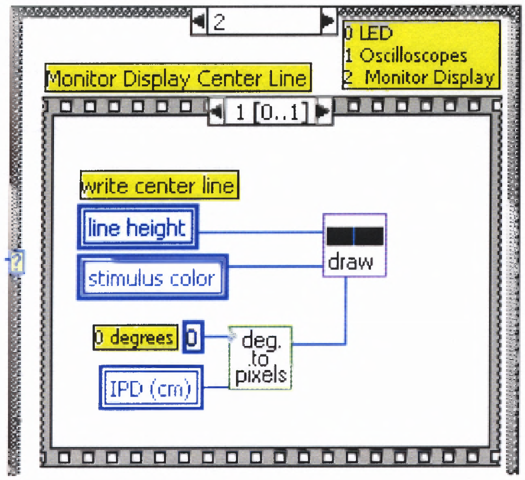

Figure 2.14 A line at midline is shown until the subject presses the button. This thesis developed a sub-virtual instrument (sub-VI) called *degrees to pixels converter* (outlined in green), which converts degrees to pixels for the computer to comprehend. Draw.vi shown outlined in purple was set to the default stimulus type of drawing a vertical line.

This section of the program then sets where the line stimulus will appear by a set of five cases, each set to one of the five calibration positions.

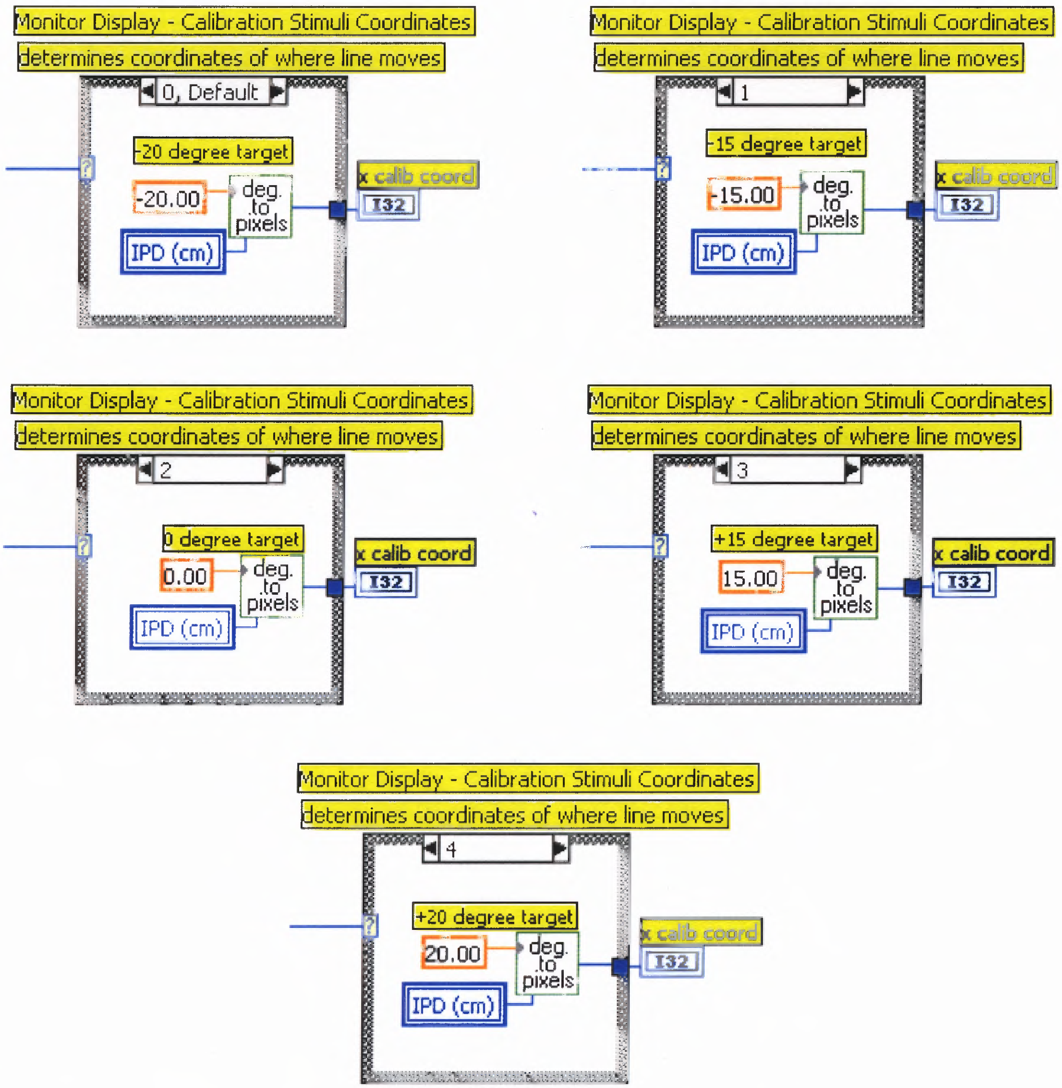

Figure 2.15 These cases, zero through four, direct the five positions of the stimulus during five-point calibration.

The following images indicate the section of the program where actual line stimulus presentation occurs.

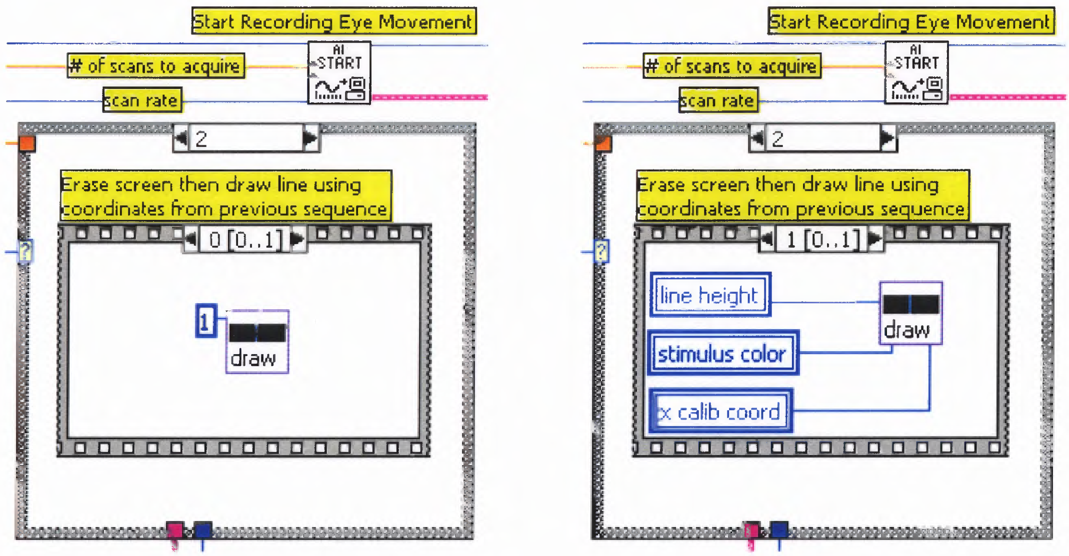

Figure 2.16 This sequence first erases the picture indicator then draws a vertical line stimulus using the coordinates previously specified.

2.4.3 Stimulus Selection

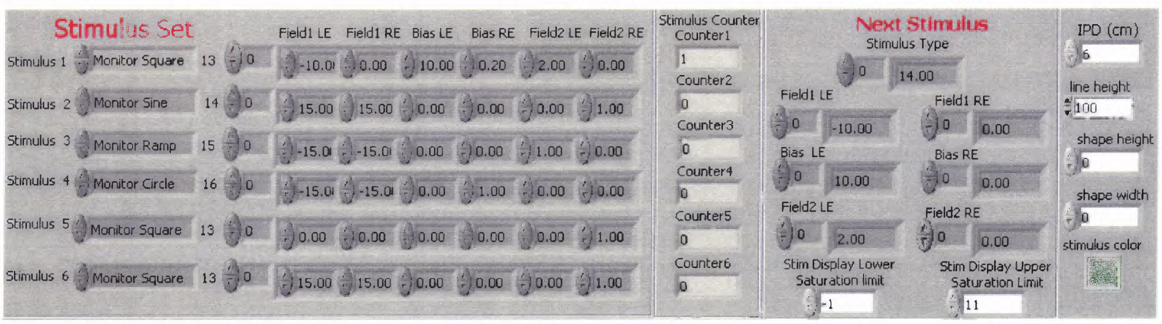

Figure 2.17 The front panel of Vision Research Program 3.0.

Figure 2.17 illustrates the front panel of the modified Vision Research Program 2.0, now Vision Research Program 3.0 (Alvarez, et al., 2003). This front panel serves as an interface between the operator and the computer. On the left, the operator can select up to six stimulus types at a time and their parameters. These parameters are currently labeled for vergence experiments, but relate to monitor stimuli in the following manner:

Table 2.2 Corresponding Parameters for Vergence and Monitor Display

Vergence	Field1 LE	Field1 RE	Bias LE	Bias RE	Field2 LE	Field2 RE
Monitor Display	x_left	x_center	x_right	frequency	cycles	-----

X_left is the left boundary of the stimulus, while *x_right* is the right limit. *X_center* is where the stimulus begins in each experimental trial. The operator enters these values in degrees. The *frequency* is the stimulus speed entered in Hertz while *cycles* is the total number of periods in one experimental trial. These two parameters determine the length of each experiment. The right side has operator controls of interpupillary distance, line height, shape height, shape width, and stimulus color which all correspond to stimuli types 14 through 16, for monitor display. Stimulus type 14 is a sine wave, type 15 is a ramp, and type 16 is an oscillating circle.

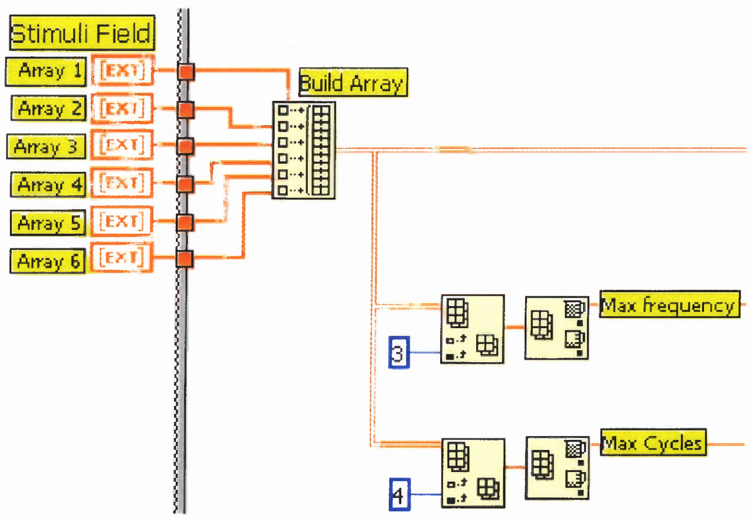

Figure 2.18 Diagram of stimuli array corresponding to the maximum of six stimulus types and their parameters. The array was indexed for to determine buffer size.

Vision Research Program 2.0 builds a six by six array of the six stimuli and their parameters (Alvarez, et al., 2003). A dynamic buffer size was developed for monitor-displayed stimuli by isolating the maximum frequency and number of cycles in Vision Research Program 3.0. This buffer size was designed to be sufficient for greatest frequency and number of cycles. If the buffer is too large, it will slow down program execution. As previously mentioned, the program displayed 250 samples per second since this was the lowest sampling rate that produced flicker-free display without delay. This value was divided by the maximum frequency to determine the maximum number of samples in one period. This value was multiplied by the maximum number of cycles to calculate an exact buffer size if a stimulus was of the greatest frequency and number of cycles. This buffer size was multiplied by five to generate more robust memory allocation to guard against computer malfunctions.

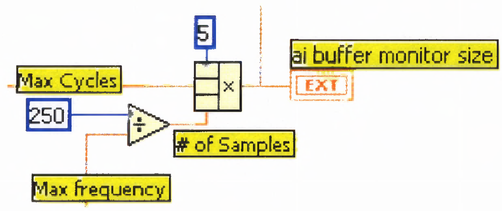

Figure 2.19 Diagram of buffer size calculation.

2.4.4 Square Wave

The Vision Research Program 2.0 has a square wave stimulus at the beginning of an experiment to ensure proper eye movement monitor placement. A subject is asked to saccade from side to side at two targets as the operator adjusts gain and centers the response signal on the eye movement monitor as well as adjusts the eye movement monitor on the subject.

This thesis developed a toggling line of square wave behavior for the same purpose for monitor display experiments between ±20 degrees, which was programmed to continue toggling until the operator pressed a button to proceed to the experimentation part of the code. This involved: the erasure of the picture indicator, presentation of a -20 degree stimulus for a total of two seconds, then erasure of the picture indicator, then display of a +20 degree stimulus for two seconds, repeatedly.

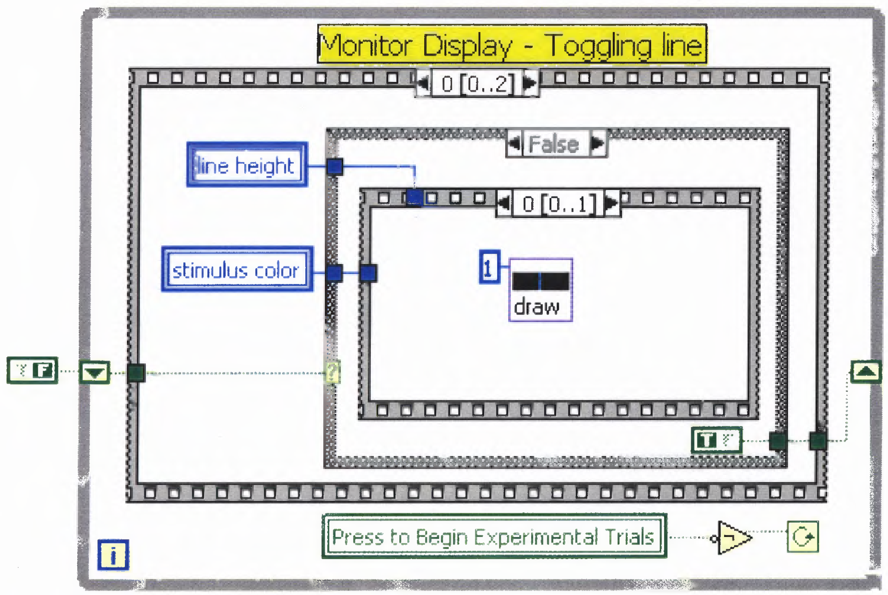

Figure 2.20 The first phase of the false case in displaying the toggling line. The picture indicator area is erased.

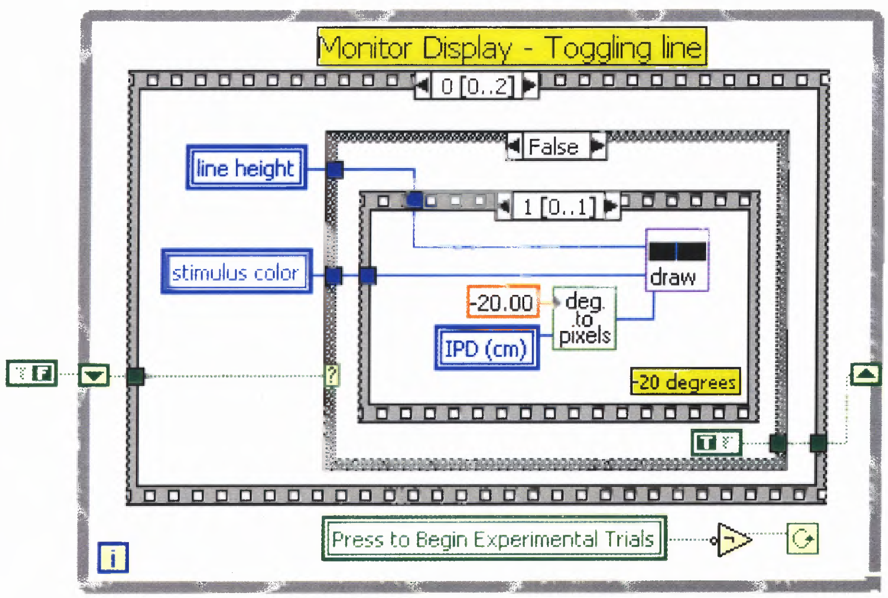

Figure 2.21 The second phase of the false case in displaying the toggling line. A vertical line of specific line height and color is drawn at –20 degrees.

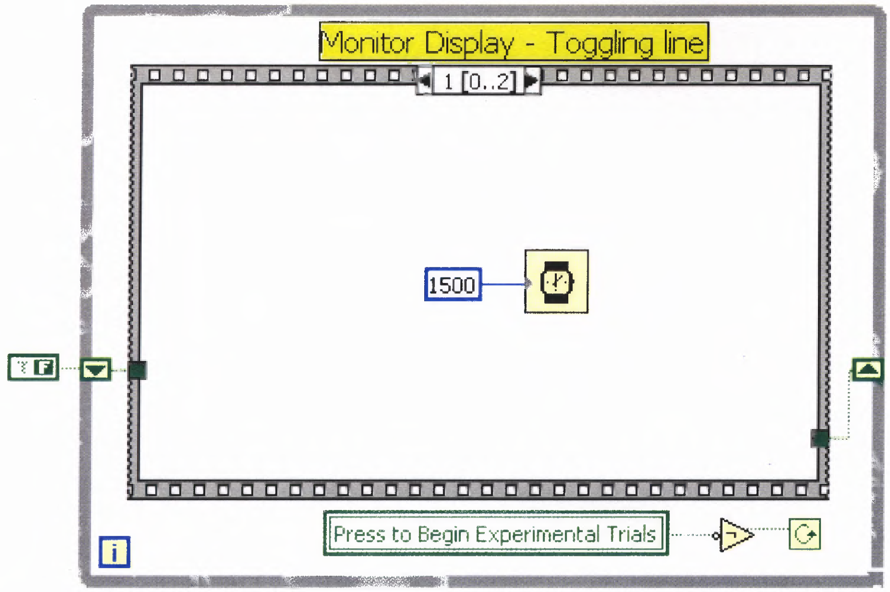

Figure 2.22 The next step in the sequence in displaying the toggling line. A wait state of 1500 milliseconds allows the vertical line to be shown for this duration. The third stage (2 of 0 to 2) of the sequence contains an additional 500-millisecond wait while allowing the operator to hold the line in a position if desired (Daftari, 2003).

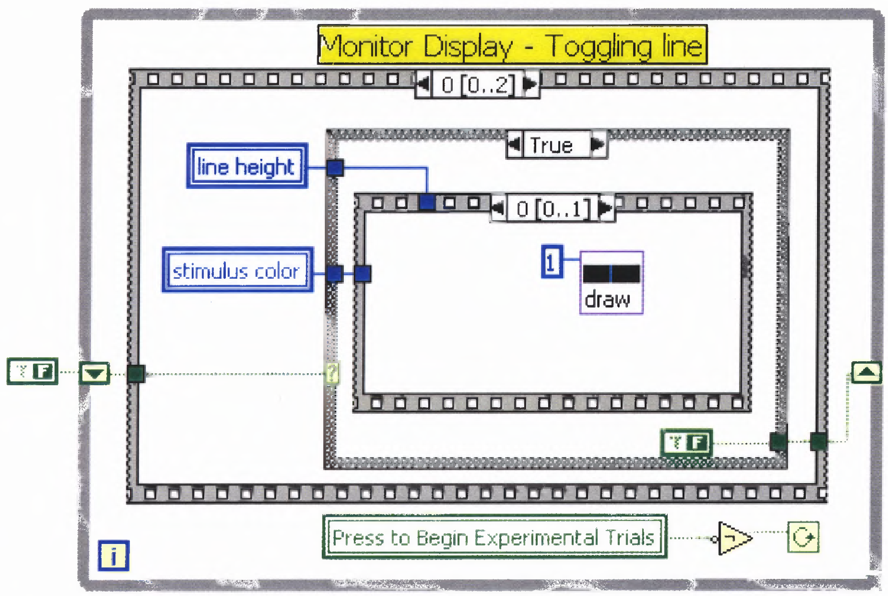

Figure 2.23 The first step in the true case displaying the toggling line. The entire picture indicator is erased to eliminate the –20-degree line.

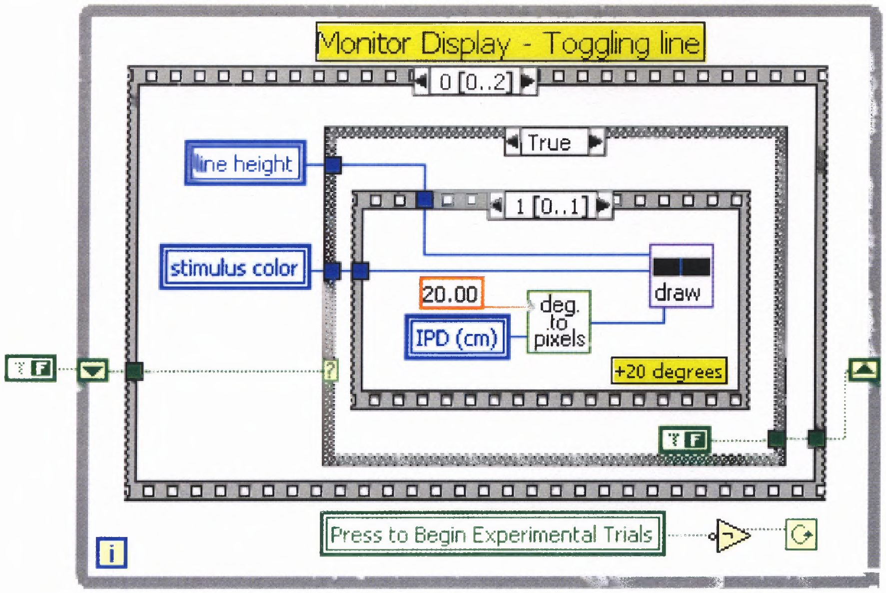

Figure 2.24 The second step of the true case in displaying the toggling line. A vertical line is drawn at +20 degrees. Then the sequence moves on to the stage in Figure 2.24.

2.4.3 Sine Wave

Numerous smooth pursuit experiments by Lisberger (1981, 1985 1987), Yarbus (1967), and others presented subjects with sinusoidal targets. Due to their periodic nature, sinusoidal targets are easier for subjects to follow and predict.

This thesis created a sinusoidally moving stimulus for monitor display. The operator can enter its center, left and right limits in degrees, as well as frequency and the number of cycles. Since the sinusoidal target moved twice as fast across the screen as a ramp target at the same frequency, it possesses a smaller range of flicker-free capability. This range includes frequencies of 0.33 Hz or less for amplitudes from -15 to +15 degrees of eye movement in real time ± 2 milliseconds. This complies with Yarbus' finding that smooth pursuit occurs at sinusoidal target frequencies of 0.33 Hz or less.

The development of the sine wave required the use of an array and dynamic timing. An array of a sine wave is created during the time that a subject is presented with a center line as a starting point. This array contains samples of one period of a sine wave. The number of samples is determined by the frequency where 250 samples are transmitted every second of an experimental trial. The amplitude of the sine wave is calculated from the difference of the right and center parameters. The sine wave is offset to begin at the center parameter.

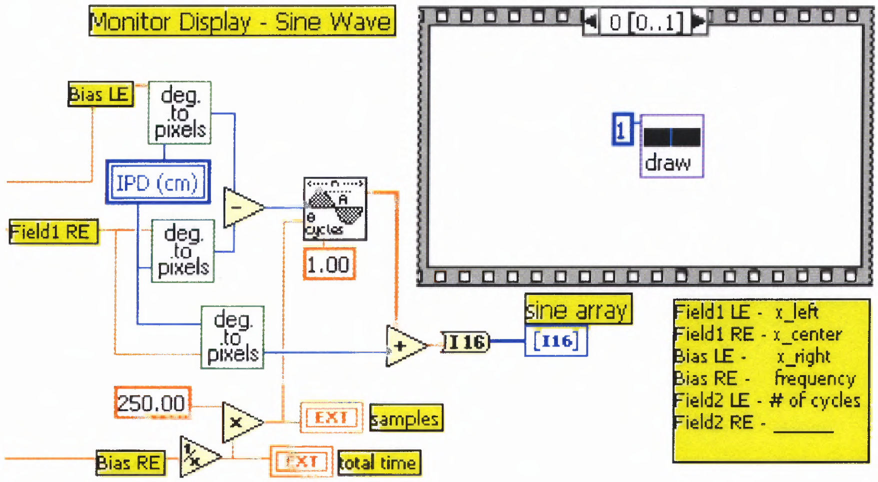

Figure 2.25 Creation of an array of samples of a sine wave during the erasure of the picture indicator.

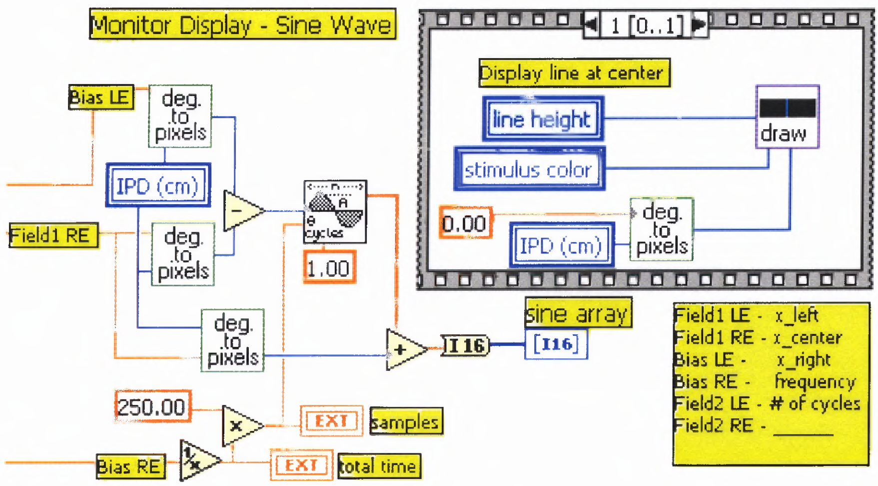

Figure 2.26 Creation of an array of samples of a sine wave during the presentation of a center line.

The stimulus is displayed 250 times per second while AI Read.vi scans at 1000 samples per second from the eye movement monitor. AI Start.vi is configured for the number of scans to acquire. This number is determined by the number of samples per period multiplied by the number of cycles (periods) and four. This value of four allows for a scan rate four times faster than the display rate while maintaining appropriate period timing.

For example, if the frequency is 0.25 Hz then the total number of samples in one period is 250 multiplied by the inverse of the frequency, this yields a sample size of 1000. If the number of cycles is two, then the number of scans to acquire is 8000. So at 1000 samples per second, each period would last four seconds, which is 0.25 Hz.

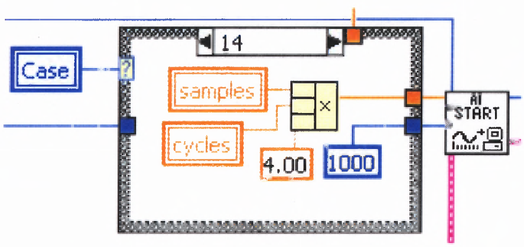

Figure 2.27 Number of scans to acquire.

Once AI start is configured, the sine wave is ready to be sent to the stimulus displays and data from the eye movement monitor is ready to be acquired. To accomplish this, three for-loops are implemented, with the innermost loop making 250 iterations. For each iteration, a line is drawn and the previous line drawn over with the same color as the background. The location of the line drawn is determined by the sine wave array built earlier. The location of the line to be erased is calculated by first shifting the sine array down so that it is behind by one value. After the line is drawn four scans are read and built into an array. Reading in four samples for every line drawn maintains the two different scan rates. The array is built for the purposes of sending it to a graph when the trial is complete. After 250 iterations, 250 lines are drawn and 1000 scans are acquired from the eye movement monitor. This is then repeated by the total amount of time that the period should last.

For instance, if the frequency is 0.25 Hz, then a period should last four seconds. Therefore, the middle loop would repeat four times. The outermost for-loop is controlled by the number of cycles. When the two inner loops are completed, one period will have been sent to the stimulus display. It is then repeated by the number of cycles. Once all looping is completed an array is sent to a waveform graph to be displayed as data from the eye movement monitor is saved to an ASCII file.

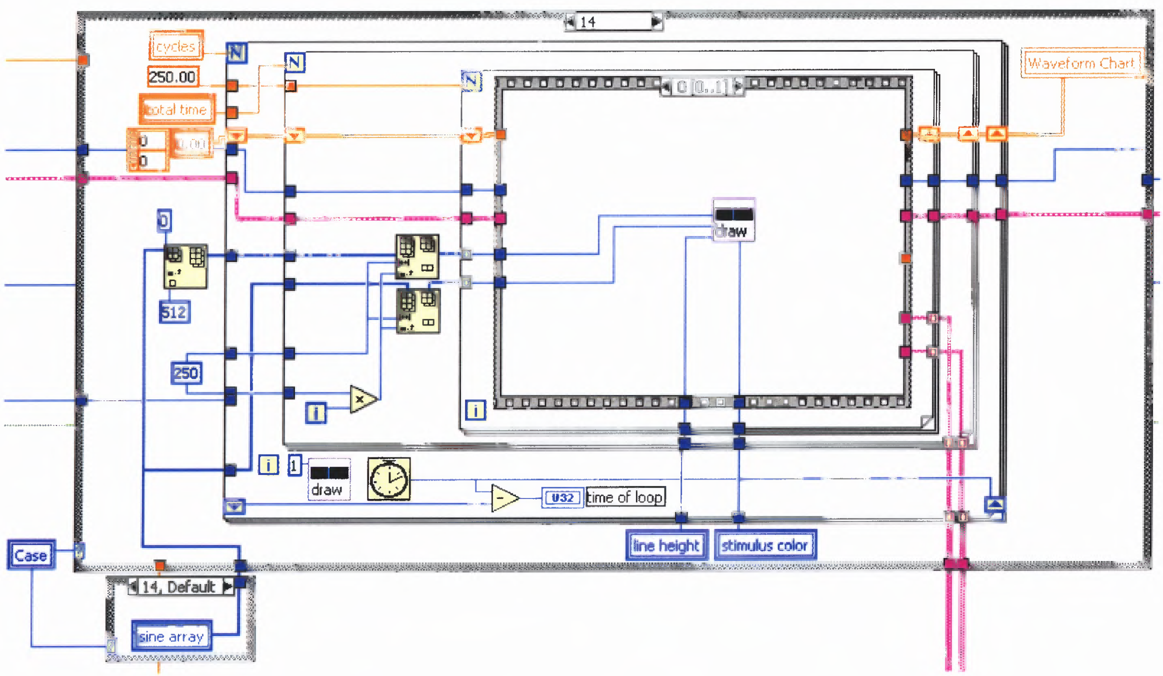

Figure 2.28 The zero frame of the sequence draws a line while erasing the previous line.

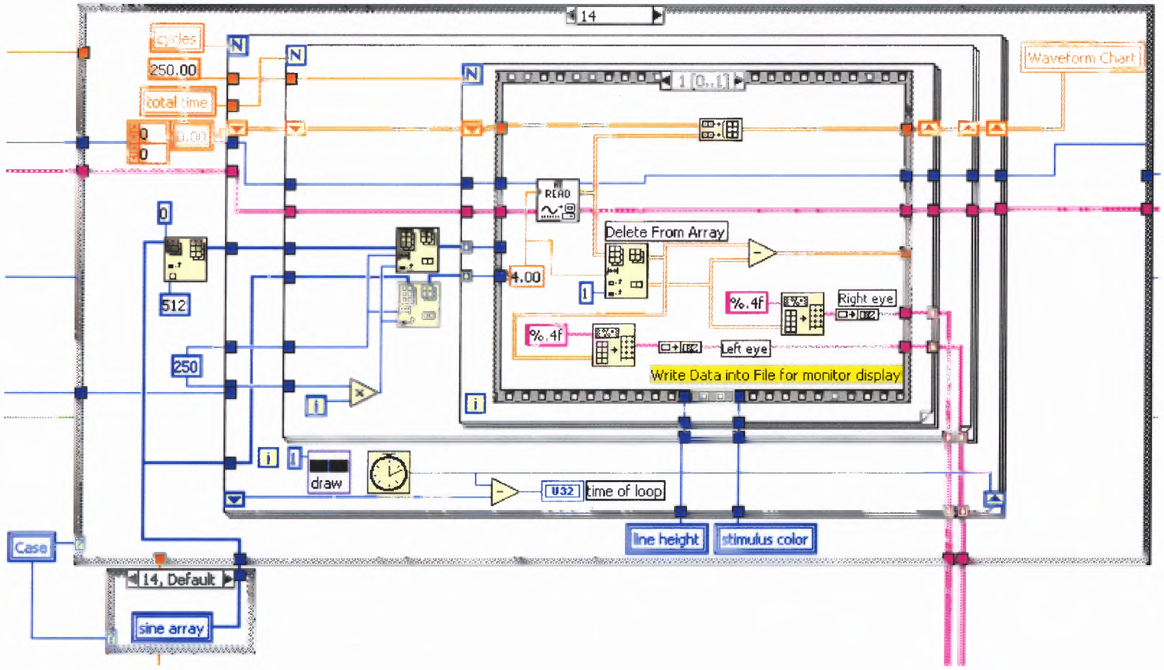

Figure 2.29 Frame one of the sequence reads in four samples from the eye movement monitor.

2.4.3 Ramp

In 1965, Robinson found that with ramp target motion, smooth eye velocity is usually only possible with target movements at speeds of 30 degrees/second or less. In a later study, Meyer and his colleagues presented subjects with non-predictable ramp stimuli to determine the upper limit of smooth pursuit velocity to be 87 degrees/second (1985). Varied ramp stimuli eliminate anticipation associated with periodic, predictive tracking (Meyer et al., 1985).

This thesis programmed a vertical line stimulus with ramp behavior moving from left to right (-15 to +15 degrees) for monitor display in real time ±1 millisecond for frequencies less than or equal to 0.7 Hz. Similar to the sine wave stimulus, the operator can manipulate the center, starting and ending points (in degrees) which correspond to the stimulus amplitude of the ramp as well as frequency and number of cycles which correspond to the time duration of the experimental trial.

The development of the ramp stimulus closely follows development of the sine wave stimulus. The only difference is the parameters used in the creation of an array of a sampled ramp. While the sine wave used the right and center parameters, the ramp uses *left* and *right* parameters as beginning and ending points of line stimulus movement.

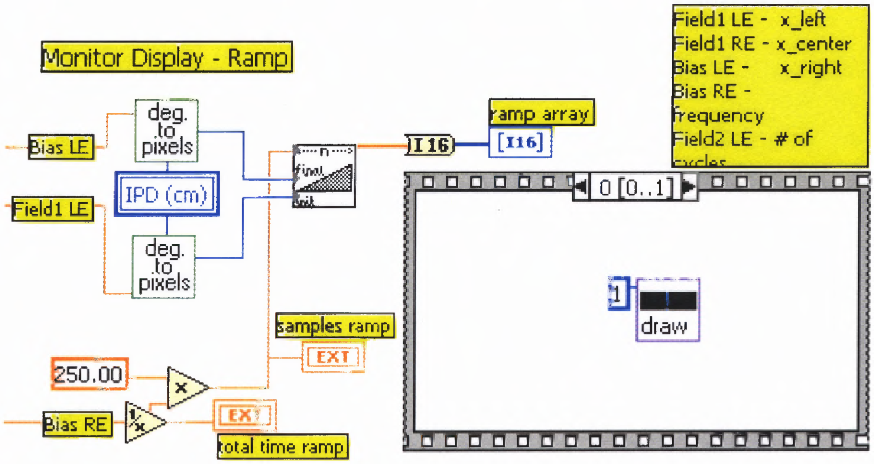

Figure 2.30 Creation of an array of samples of a ramp during the erasure of the picture indicator.

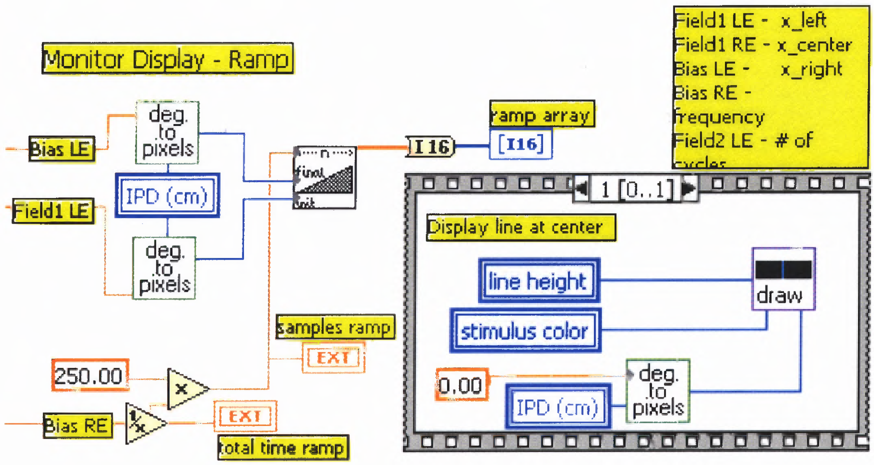

Figure 2.31 Creation of an array of samples of a ramp during the display of a line stimulus.

2.4.5 Oscillating Circle

This study developed an oscillating circle stimulus as a proof of concept and for use in future projects. One of these projects described in *Future Research* involves training subjects to smoothly follow an afterimage target induced by a photic stimulator. Since the photic stimulator normally evokes circular afterimages, a circular stimulus was chosen to be appropriate for that study. Traveling between -15 and +15 eye movement degrees on the monitor, the circle was able to display flicker-free at frequencies of 0.33 Hz or less in real time ±4 milliseconds.

The oscillating circle was developed similarly to the sine wave stimulus. Some mathematical manipulation was made so that the center of the circle rather than its left edge appeared at the operator-entered left, center, and right parameters. Also different from the sine wave are the operator-entered parameters such as shape height, rather than line height, and shape width.

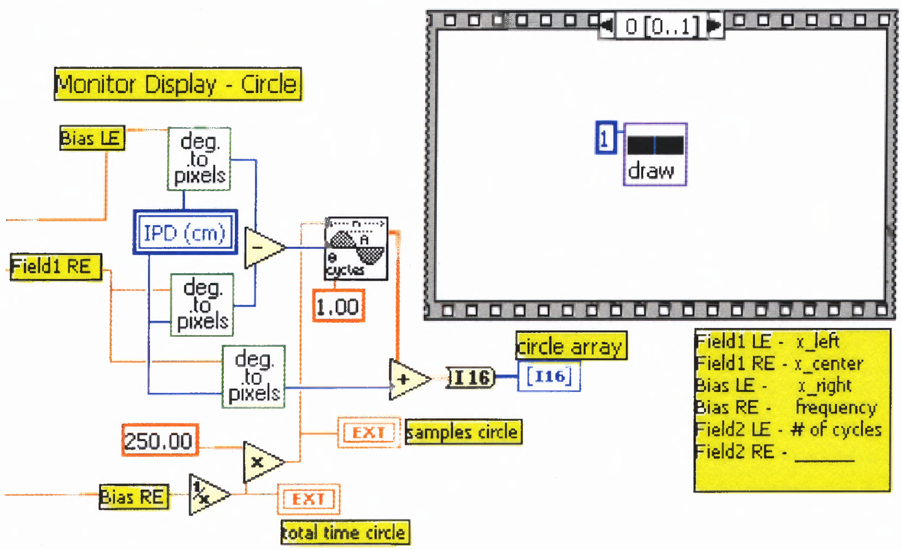

Figure 2.32 Creation of an array of samples of a sine wave during the erasure of the picture indicator.

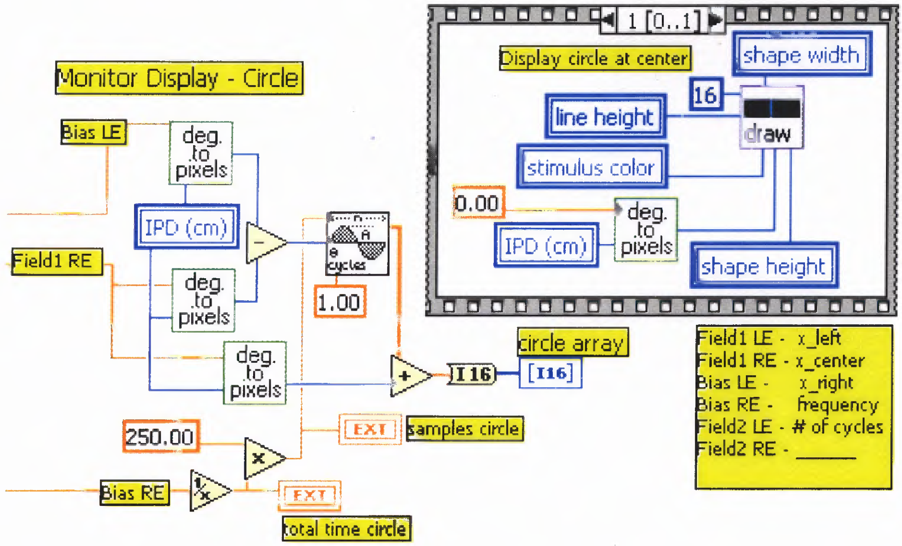

Figure 2.33 Creation of an array of samples of a sine wave during the display of a circle.

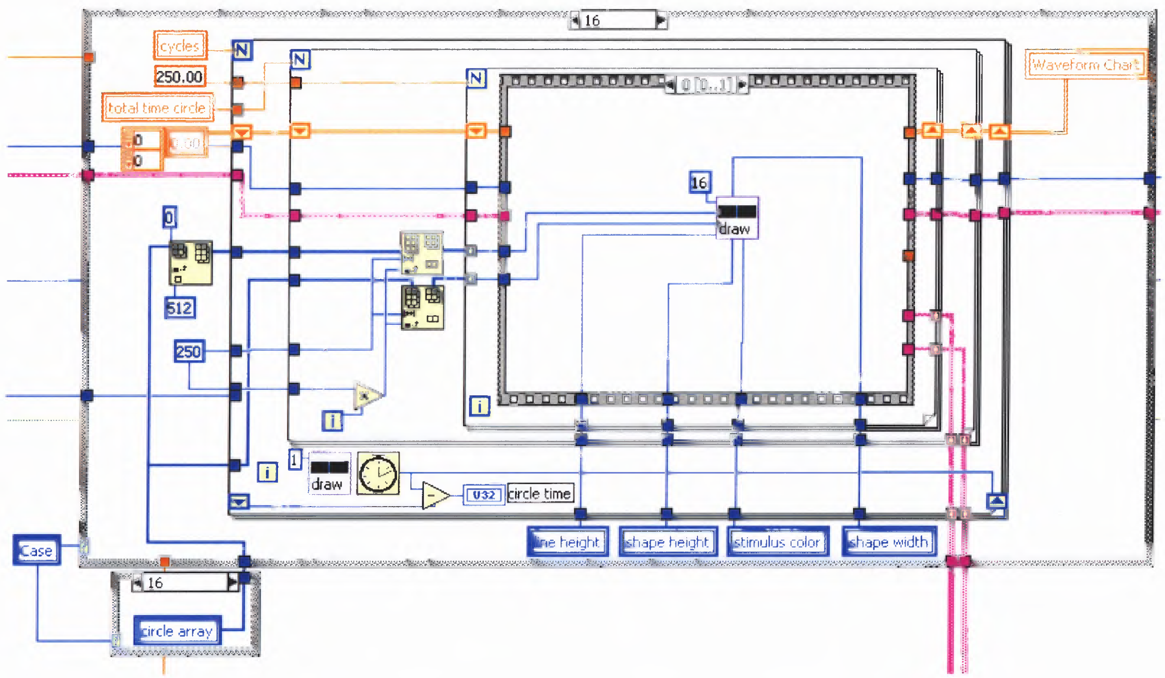

Figure 2.34 The zero frame of the sequence draws a circle while erasing the previous one with a black rectangle.

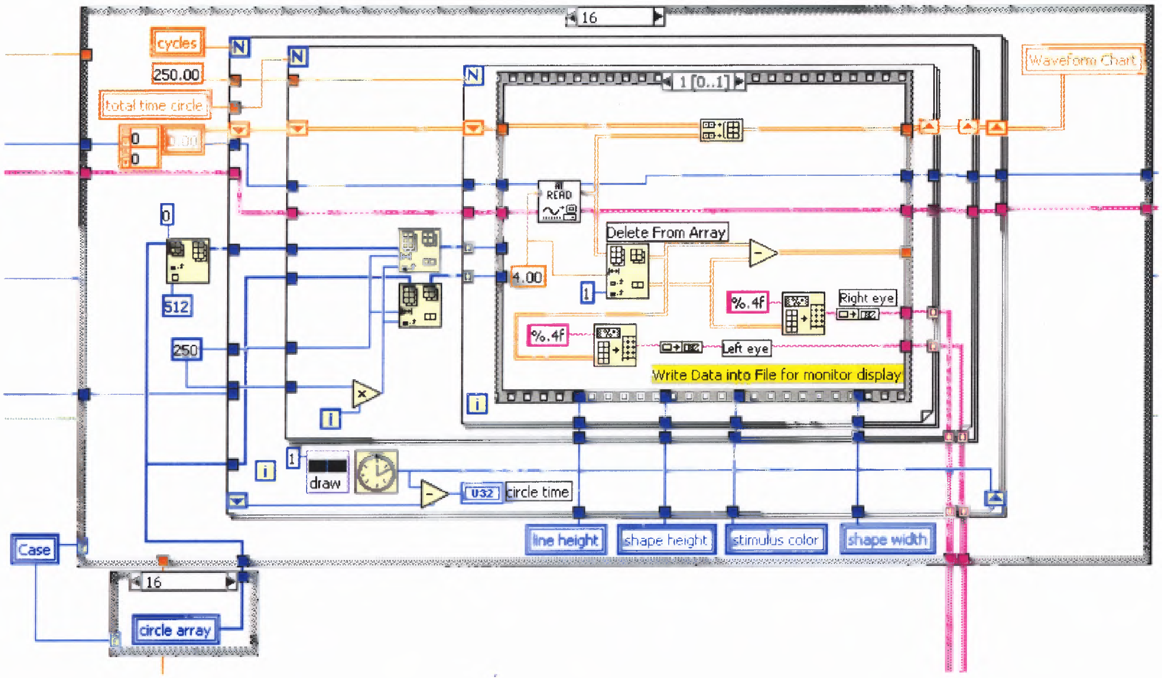

Figure 2.35 Frame one of the sequence reads in four samples from the eye movement monitor.

CHAPTER 3

EXPERIMENTAL METHODOLOGY

The main objective of this study was to create a new stimulus display for smooth pursuit eye movements that offers improved functionality compared to the existing stimulus display. Those improvements include:

1. Increased range
2. Different colors
3. Different shapes
4. Different line heights
5. Adjustment for IPD
6. Framework for more advanced stimuli.

The new apparatus was verified with the use of LabVIEW in controlling stimulus display on a monitor for smooth pursuit eye movement experiments. This occurred in two comparisons:

1. *Monitor versus Light-Emitting Diode Calibration.*
2. *Monitor versus Oscilloscope Display in Smooth Pursuit.*

3.1 Common Devices

Common to both experiments were the eye movement tracker and controlling computer. The Skalar Iris model 6500, a limbus-tracking device, recorded data at a sampled rate of 1000 Hz for the first experiment and 200 Hz for the second. This eye movement monitor has a resolution of 2 minutes of arc and a linearity of $\pm$25 degrees (Cambridge Research

Systems, Inc., 1999). This instrument was placed on the subject's head and adjusted to the left and right eye. It collected data from each eye where left and right eye movements were individually stored to be analyzed offline. A Dell Optiplex GX240 Pentium IV, 1.70 GigaHertz (GHz) computer with 256 MB of RAM operating with Microsoft Windows XP Professional 2002 ran LabVIEW 6i. This computer contained a data acquisition (DAQ) board, model 6024e, from National Instruments which recorded incoming analog signals as voltage values and output digital signals to the oscilloscope and LEDs. This DAQ card has eight digital inputs or eight outputs that read or write 5 volts. These bits cannot be used simultaneously for input and output functions.

Also mutual to both experiments was the ViewSonic E70fb 16-inch (12 inches or 32.4 cm wide) color flat screen monitor. The apparati also involved a MatroxG video card with 256 MB of memory and outputs for up to three monitors (Matrox Graphics, Inc., 2003). This thesis used two monitors, one for a control panel and the other for stimulus display.

3.2 Monitor versus Light-Emitting Diode Calibration

The purpose of comparing five-point calibration on a monitor to the same with LEDs was to determine the validity of the use of monitor display for horizontal smooth pursuit eye movement experiments. The LEDs were used for saccade experiments in which eyes moved horizontally in tandem. This experiment validated the use of a computer monitor stimulus display for horizontal eye movements.

3.2.1 Apparatus

The control apparatus had five identical green LED targets situated at 0 (midline), $\pm$15, and $\pm$20 degrees, with the 0 degree target at 57 cm away from the subject. The experimental apparatus displayed targets on the previously described computer monitor at 0 (midline), $\pm$15, and $\pm$20 degrees, with the 0 degree 40 cm away from the subject.

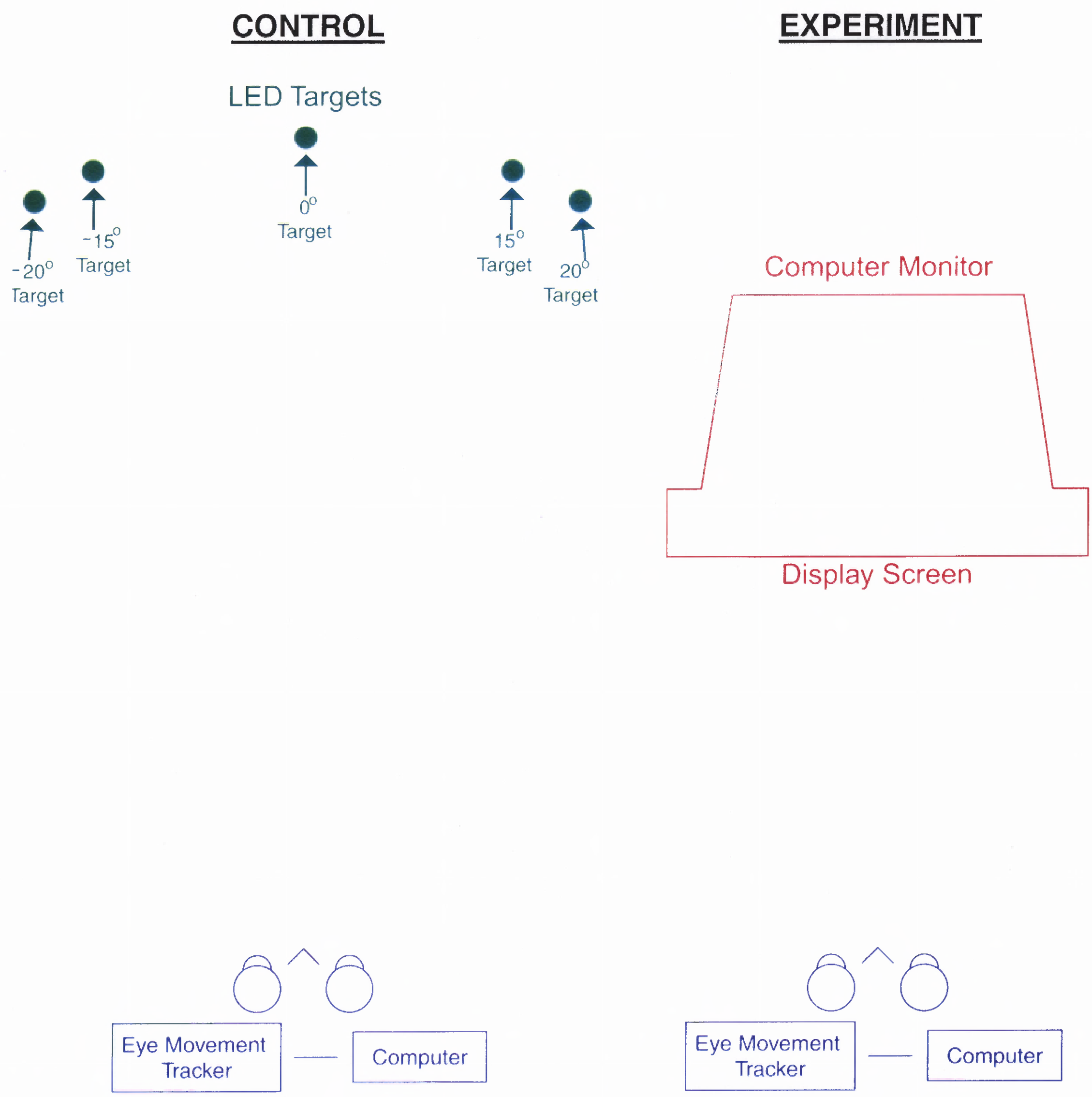

Figure 3.1 Apparatus for five point calibration. The image on the left depicts the control set-up while the one on the right represents the experimental apparatus.

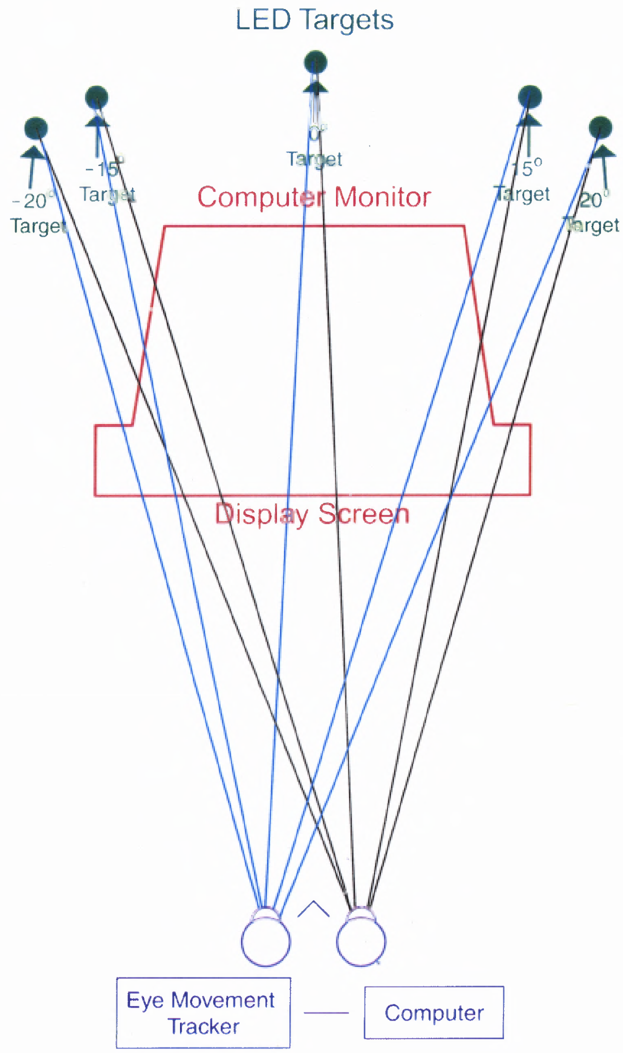

Figure 3.2 Overlay of control and experimental apparati. The computer monitor was placed closer to the subject than the LEDs to stimulate the same range of eye movement.

Figure 3.3 A subject inside the control apparatus.

Figure 3.4 The experimental apparatus including a ViewSonic monitor for stimulus display and chin and adjustable cheek rests. A +20-degree target is shown on the screen.

3.2.2 Experimental Protocol

The same subject with IPD of 6 cm participated for both calibrations. The subject was first seated, and then asked to center and stabilize his head with a chin rest that extended to lower cheeks. The subject was asked to push a trigger when he felt ready to keep his eyes open, and then look at a target for five seconds. This subject did this for each of five targets for LED and monitor calibration for five trials apiece.

3.2.3 Data Acquisition

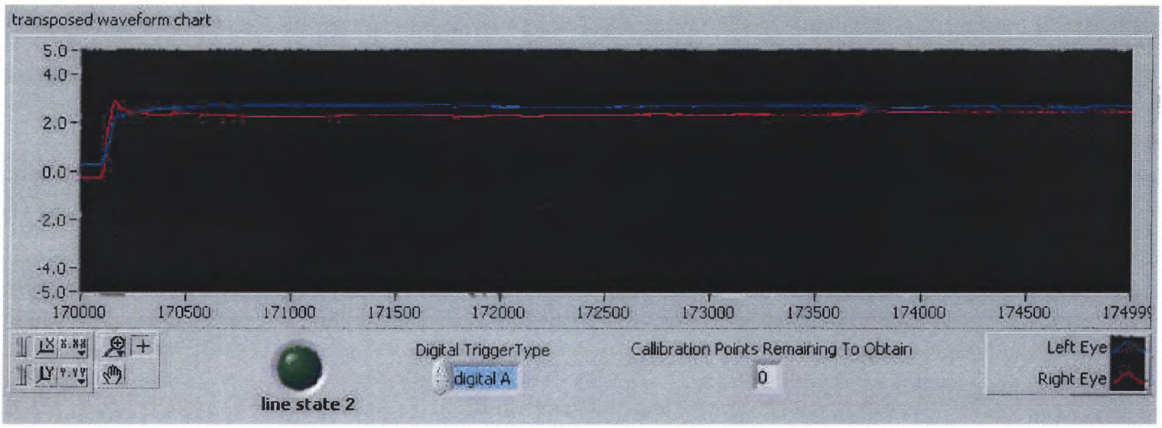

Figure 3.5 A control panel example of a five-second eye movement recording for fixation on an LED target at +20 degrees originally programmed into Vision Research Program 2.0 with LabVIEW.

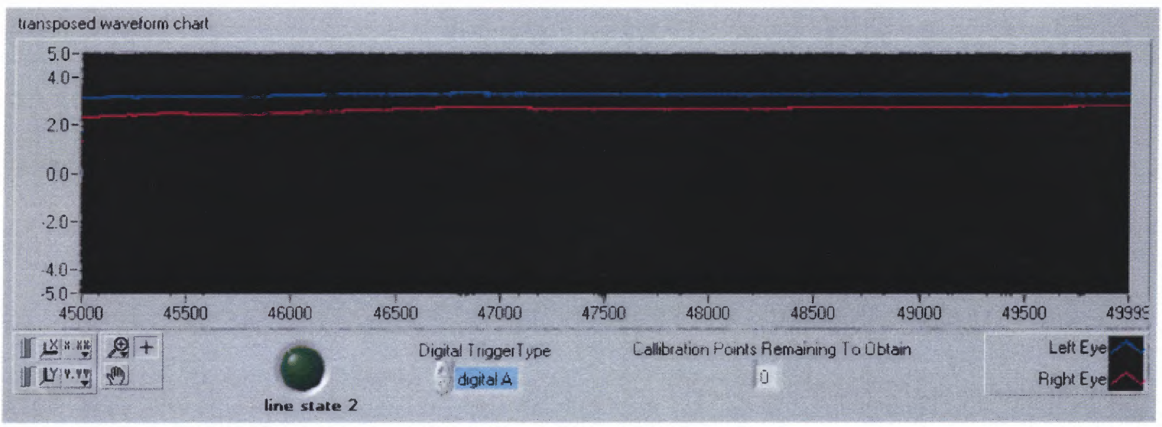

Figure 3.6 A control panel example of a five-second eye movement recording for fixation on a monitor target at +20 degrees programmed with LabVIEW.

The Skalar Iris model 6500 monitored eye position for five seconds while LabVIEW recorded the voltage value at each position at 1000 Hz. The photodetectors on the limbus tracker determined the position of the left and right eyes from the differential of infrared light reflected off the eye. The black box of the limbus tracker transduced this to voltage, then LabVIEW converted this value to degrees.

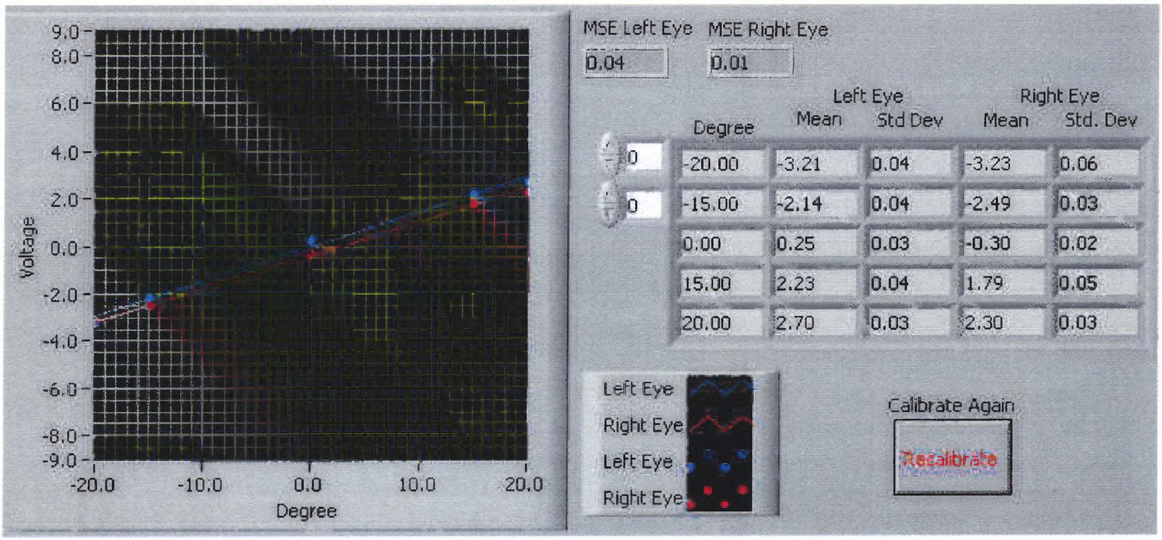

Figure 3.7 Five-point calibration for left and right eyes on the control panel. Means and standard deviations for each of five targets are shown on the right. This was originally programmed into Vision Research Program 2.0 in LabVIEW.

3.2.4 Data Analysis

Five-point calibration on the computer monitor at five positions, 0, $\pm$ 15, and $\pm$ 20 degrees were compared with five-point calibration that successively illuminated five light-emitting diode (LED) targets at the same positions for five trials each. In previous saccade experiments, where the eyes moved in tandem to a target, Vision Research Program 2.0 performed linear regression on averaged voltage-to-degree results (Daftari, 2003). The results followed a linear equation with small standard deviation (0.01 to 0.11). The same program modified for monitor display performed linear regression on averaged voltage-to-degree results.

Results were compared in terms of the square of the Pearson product moment correlation coefficient, *R*. The square of this coefficient mathematically indicates how strongly related two sets of data in this study are related. The R^2 value always falls between zero and one and a value close to zero indicates poor correlation. In this case, R^2 close to one indicates a high correlation between voltage and eye position in degrees.

3.3 Monitor versus Oscilloscope Display in Smooth Pursuit

This study investigated LabVIEW-controlled stimulus display on a computer monitor in a pursuit eye movement experiment. The experimental portion of this study involves tracking pursuit of a target on a computer monitor, while the control portion will track pursuit of a similar target on an oscilloscope (control).

3.3.1 Apparatus

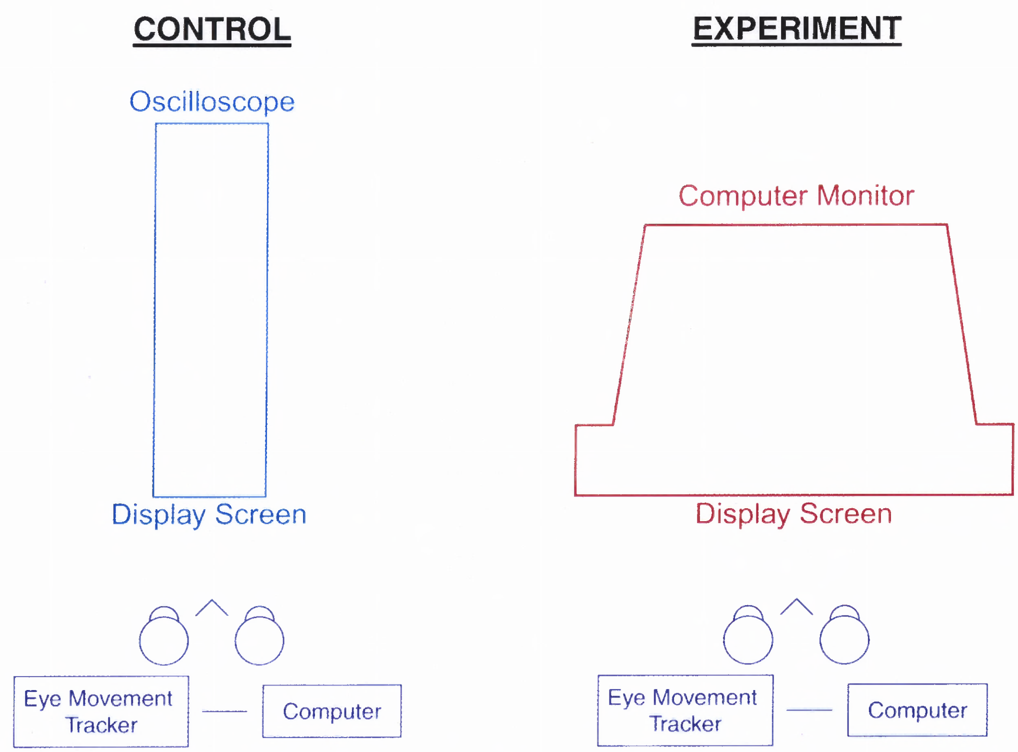

Figure 3.8 The left image depicts the experimental set-up for smooth pursuit on an oscilloscope (control). The right diagram represents the experimental set-up for smooth pursuit on a computer monitor (experiment).

The control set-up involved an oscilloscope with a 3.15-inch (8 cm) wide screen placed 22 cm from the subject while the experimental set-up includes the ViewSonic monitor from the previous experiment also placed 22 cm from the subject. At this distance (roughly nine inches) from the subject, a maximum of only $\pm$10 degrees of eye movement can be achieved per eye. Also at this distance, the flatness of the oscilloscope screen and the monitor caused a maximum of 4.1 percent error at the extremes of $\pm$10 degrees.

CONTROL **EXPERIMENT**

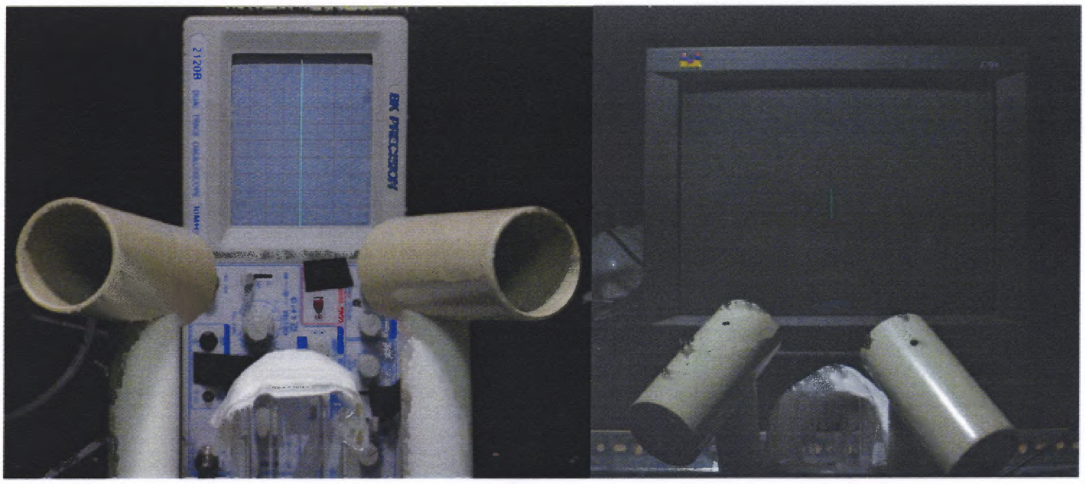

Figure 3.9 The control and experimental set-up for smooth pursuit on an oscilloscope (left) and computer monitor (right).

The portion of the Vision Program 2.0 (Alvarez, et al., 2003) controlling oscilloscope stimulus display had the ability to present subjects with an oscillating line for ten seconds at specific frequencies: 0.1 Hz, 0.2 Hz, 0.5 Hz, and 1 Hz while sampling eye movement data at 200 Hz (Herrera, 2003). This experiment was interested in stimulus presentation at 0.2 Hz frequency for two reasons:

1. The value complied recommended range of frequencies of 0.33 Hz and lower which are optimal smooth pursuit eye movements.
2. Two periods of five seconds each could be presented with a stimulus frequency of 0.2 Hz rather than only one period of ten seconds at 0.1 Hz.

Thus, both the control and experiment portions of this study presented the subject with a stimulus oscillating at 0.2 Hz while sampling eye movement data at 200 Hz. A second experiment involved presenting the subject with a 0.2 Hz target while sampling eye movement data at 1000 Hz, since this sampling rate was optimal for the intended purposes in future research. In review, three validation experiments occurred:

1. A subject tracked a line stimulus between -10 and +10 degrees at 0.2 Hz on the oscilloscope with eye response sampled at 200 Hz;
2. The same subject tracked a line stimulus between -10 and +10 degrees at 0.2 Hz on the computer monitor with eye response sampled at 200 Hz;
3. The subject tracked a line stimulus between -10 and +10 degrees at 0.2 Hz on the computer monitor with eye response sampled at 1000 Hz.

3.3.2 Experimental Protocol

Horizontal eye movement data were collected with Vision Research Program 3.0 in LabVIEW in response to a vertical line stimulus oscillating at constant frequency of 0.2 Hz between ± 10 degrees for all control and all experimental trials. The subject had the choice to pause anytime if fatigued. The subject was told to visually track the target after the trigger push. A audible tone signified the end of an experimental session and indicated that a subject could blink and not create artifacts in the data.

Before the experiment, the subject was generally instructed, "After calibration is complete, look at the center target. When the lights are turned off, remain fixated in the center. Try to track the target with your eyes." The subject was then seated, head stabilized, and dark-adapted for five minutes with a dim light.

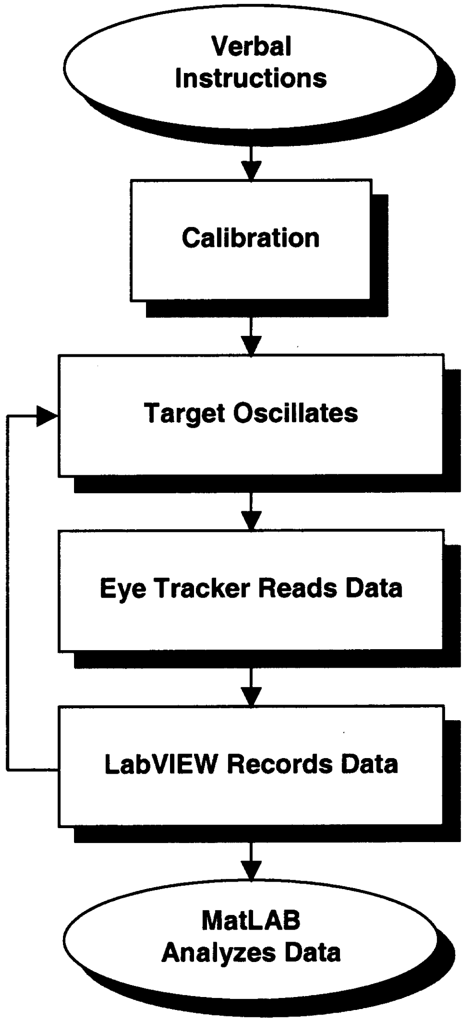

Figure 3.10 A diagram of the experimental procedure.

A custom eye tracker calibration occurred, as the subject was told to fixate on five targets 0 (midline), $^{\pm}5$, and $^{\pm}10$ degrees. The subject's eye movements were digitized then converted into degrees. After calibration, the subject was asked to fixate on the center target then push a trigger to initiate the experiment. Once the trigger was pushed, the stimulus was presented for ten seconds, following a random delay of 0.5 to 2 seconds to prevent subject prediction. Then the eye tracker read eye movement data which was recorded along with target movement by LabVIEW. The eye tracker recorded eye movement data, which was digitized by LabVIEW. Pertinent information such as stimulus given, calibration information, randomized delay and date of experiment were saved in the header. All data were saved to a data file to be analyzed off-line. The procedure repeated until 20 responses were collected per stimulus type. A diagram of the procedure is shown in Figure 3.10. Eye tracker calibration was recorded every ten experimental trials where the number of experimental trials per calibration was a variable parameter.

3.3.3 Data Acquisition

During calibration, the Skalar Iris model 6500 monitored eye position for ten seconds while LabVIEW recorded the voltage value at each position at 200 Hz for the direct oscilloscope and computer monitor comparison and at 1000 Hz to observe the advanced capabilities of the new stimulus display. The photodetectors on the limbus tracker determined the position of the left and right eyes from the differential of infrared light reflected off the eye. The black box of the limbus tracker transduced this to voltage, and then LabVIEW converted this value to degrees.

For each experimental trial, data were recorded for 10 seconds at 200 Hz. An additional set of data was recorded for ten seconds per trial at 1000 Hz on the experimental apparatus to test the ideal operating mode of the program for experiments. The type of stimulus was recorded along with eye movement data for offline analysis. Data were analyzed offline to increase system performance and allow for various types of data analysis.

3.3.4 Data Analysis

Data were analyzed from three validation experiments:

1. A subject tracked a line stimulus between -10 and +10 degrees at 0.2 Hz on the oscilloscope with eye response sampled at 200 Hz (control);
2. The same subject tracked a line stimulus between -10 and +10 degrees at 0.2 Hz on the computer monitor with eye response sampled at 200 Hz (experiment);
3. The subject tracked a line stimulus between -10 and +10 degrees at 0.2 Hz on the computer monitor with eye response sampled at 1000 Hz, since this sampling rate was optimal for future research purposes (experiment).

Qualitative data analysis involved comparing overall eye movement qualities from the experiment to those from the control. Inspected characteristics included smoothness of eye movement and phase of eye movement and stimulus movement.

Quantitative data analysis occurred in MatLAB® using a variation of the *Vision Data Analysis Program Version 2.0* as eye movement data were plotted with target stimulus movement data versus time (Semmlow, 1995; Alvarez, 1998, 2003). Two forms of timing analyses occurred including smooth pursuit latency, defined by the time it took for the eyes to reach the target, and periodicity analysis, which determined the accuracy of simultaneous stimulus display and eye movement recording.

The initial latency to target was determined by the *ginput* command which determined eye position at an operator-indicated time. This was performed on 18 to 28 trials for both the control and experiments. The average of pursuit latencies to target for all experimental set-ups was verified to be within the 80 to 130 millisecond range previously reported by Yarbus and other researchers. The average of pursuit latency for monitor display was compared with the average of pursuit latency for oscilloscope display.

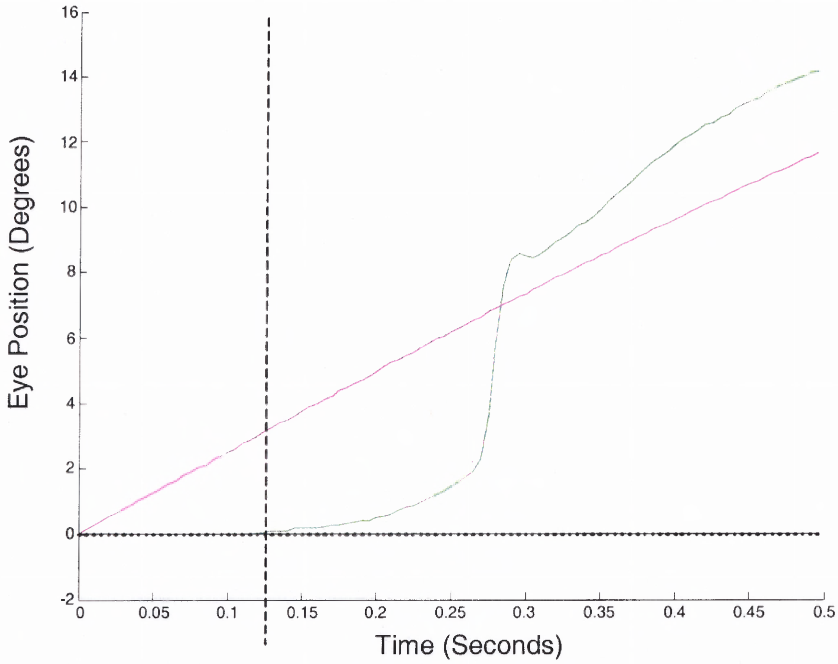

Figure 3.11 A plot of the first half-second of eye movement (green). Stimulus movement is denoted in pink. Latency analysis determined the time at which eye position initially deviated from zero. In this graph, this value falls between 100 and 150 milliseconds.

To determine periodicity of eye movements, a plot of individual left and right eye positions, summed eye positions, and stimulus position were plotted on the same graph. Peak-to-peak analysis was determined to be subjective, so a period was measured from one zero degree eye position to another zero position where the stimulus and eye movement crossed each other.

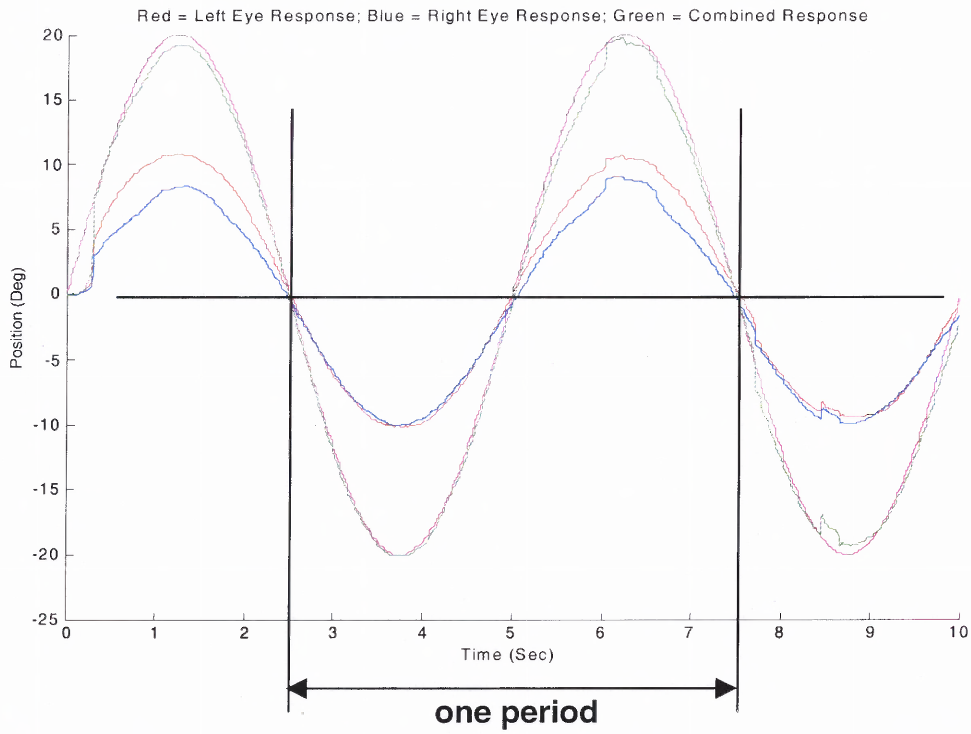

Figure 3.12 A plot of eye position due to an stimulus sinusoidally oscillating for ten seconds. Right eye movement is in blue, left eye movement is in red, combined response is in green, and stimulus movement is in pink.

A t-test assessed whether the mean of the data using the oscilloscope apparatus were significantly different from the mean of the data using the monitor set-up with a *p-value*, which ranges from zero to one. In the case of an experiment which yields the same mean between two populations, the p-value determines the probability of observing such a large difference between samples in an experiment of this size. A p-value less than 0.5 was chosen to indicate significant statistical difference between two populations, while a p-value greater than 0.5 indicated *no difference* between two populations. A p-value greater than 0.25 indicated that the results from the two populations may have come from the same population (GraphPad Software, Inc., 2002).

CHAPTER 4

RESULTS

4.1 Monitor versus Light-Emitting Diode Calibration Results

The following table presents five-point calibration results from a subject who made a saccade to, then fixation on every one of five targets at -20, -15, 0, +15, and +20 degrees for five seconds each. Five trials with monitor calibration yielded voltages ranging from -3.27 to 2.917 volts at the extreme targets of -20 and +20 degrees, respectively, while five trials with LED calibration yielded voltages ranging from -3.60 to 2.91 volts at extreme target of -20 and +20 degrees.

Table 4.1 Summary of Average Results for Calibration Using LEDs (Control) and Calibration on a Monitor (Test)

Eye Position	LED Calibration Average		Monitor Calibration Average	
	Left Eye	Right Eye	Left Eye	Right Eye
-20º	-3.3986	-3.2298	-3.0575	-3.2200
-15º	-2.4693	-2.4411	-2.1613	-2.4326
0º	0.0393	-0.1661	-0.0332	0.0169
15º	2.1255	2.1552	2.02756	1.7882
20º	2.7602	2.5852	2.8155	2.3854

Examples of raw data from both eye movement tracker calibrations from LED and monitor display follow with left eye data in red and right eye data in dark blue:

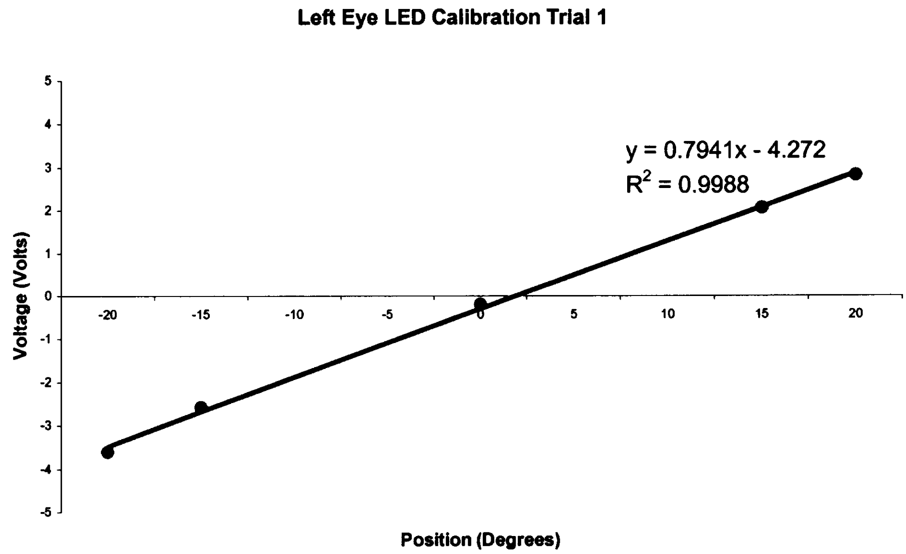

Figure 4.1 An example of eye tracker calibration with LEDs (control) as targets for the left eye.

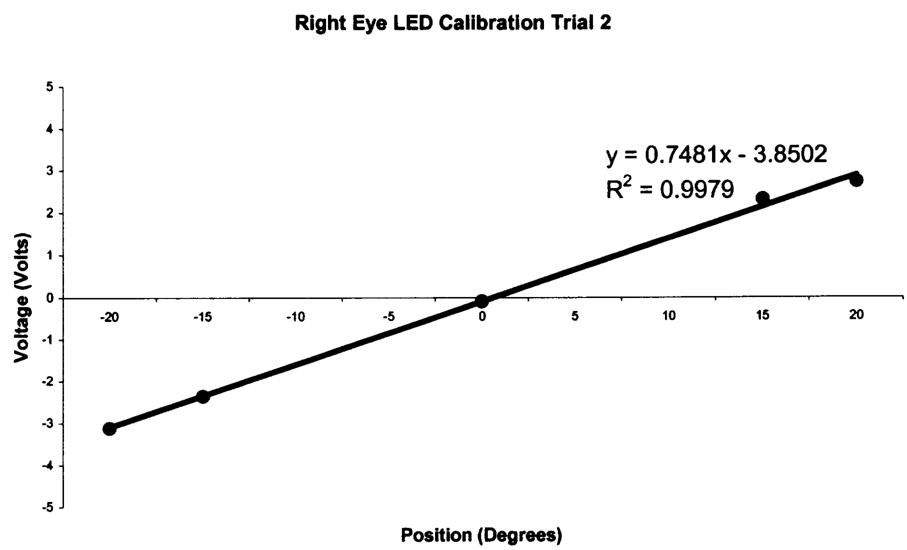

Figure 4.2 An illustration of eye tracker calibration with LEDs (control) as targets for the right eye.

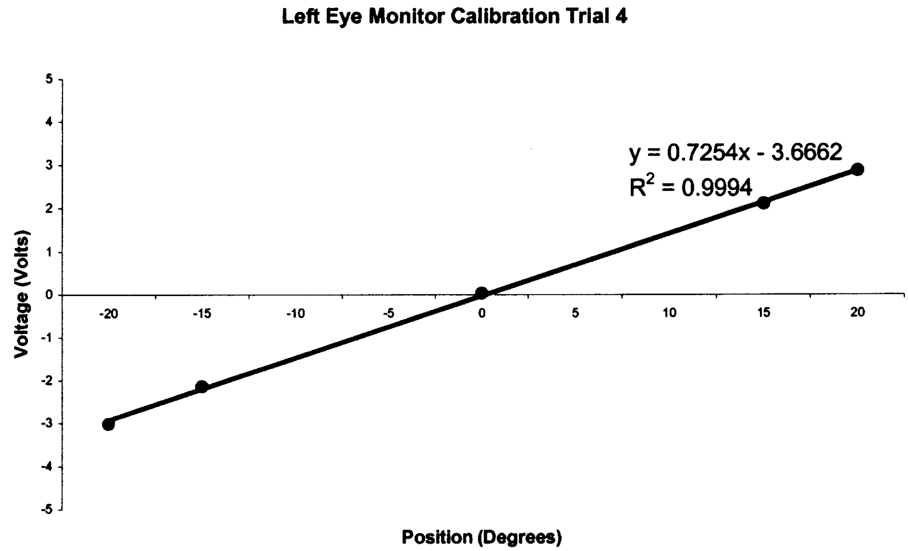

Figure 4.3 A graph of eye tracker calibration with stimuli on a computer monitor as targets for the left eye.

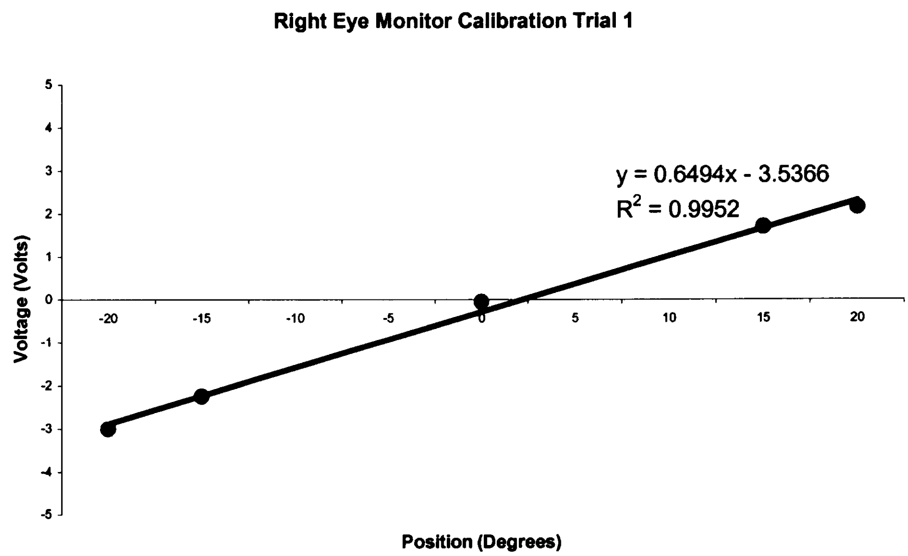

Figure 4.4 An example of eye tracker calibration with stimuli on a computer monitor as targets for the right eye.

Quantitatively, the square of the Pearson product moment correlation coefficient generated a value of 0.9971 for the left eye and 0.9981 for the right eye for LED calibration. For monitor calibration, R^2 was 0.9992 for the left eye and 0.9948 for the right eye. Values from calibration performed on the monitor display (experiment) are equivalent to data from calibration performed with LEDs (control), up to the hundredths place. Standard deviations range from 0.1033 to 0.2124 for LED calibration for the left eye, 0.0716 to 0.2771 for LED calibration of the right eye, 0.1073 to 0.3403 for monitor calibration of the left eye, and 0.0728 to 0.2255 for monitor calibration of the right eye.

Table 4.2 Summary of Standard Deviations for Calibration Using LEDs (Control) and Calibration on a Monitor Display (Test)

Eye Position	LED Calibration Standard Deviation		Monitor Calibration Standard Deviation	
	Left Eye	Right Eye	Left Eye	Right Eye
-20°	0.1526	0.1115	0.1446	0.1498
-15°	0.2124	0.0716	0.1073	0.1369
0°	0.1635	0.1011	0.1450	0.0728
15°	0.1219	0.2770	0.2413	0.2255
20°	0.1033	0.1760	0.3403	0.2011

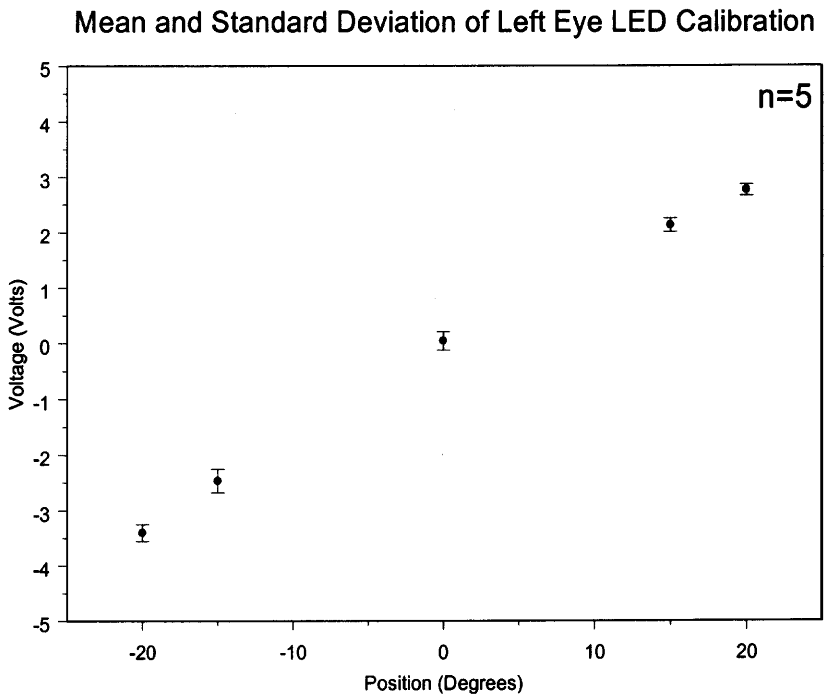

Figure 4.5 Average results from eye movement tracker calibration using LEDs are targets for the left eye. LabVIEW associates voltages from the eye tracking system with eye positions.

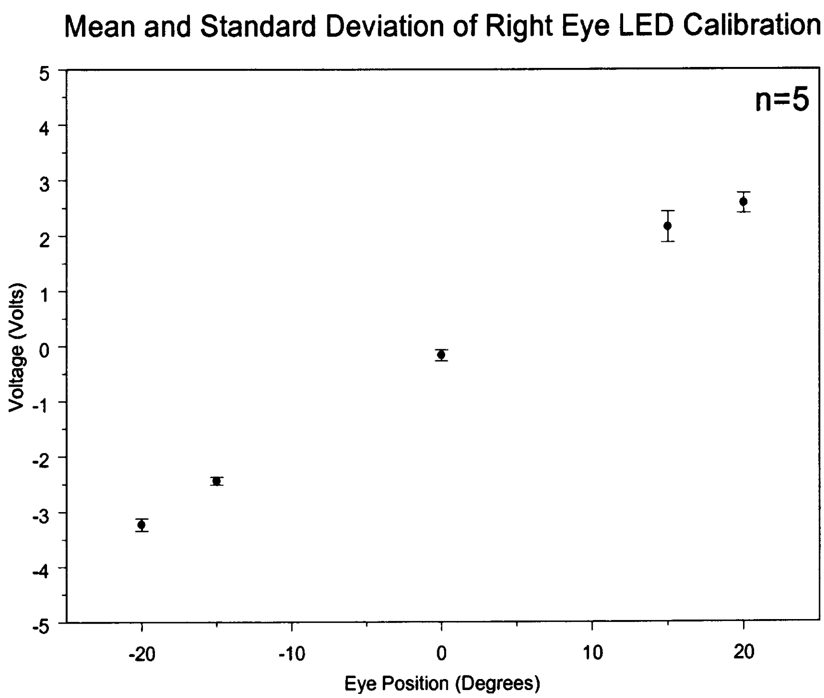

Figure 4.6 Mean results from eye movement tracker calibration using LEDs are targets for the right eye.

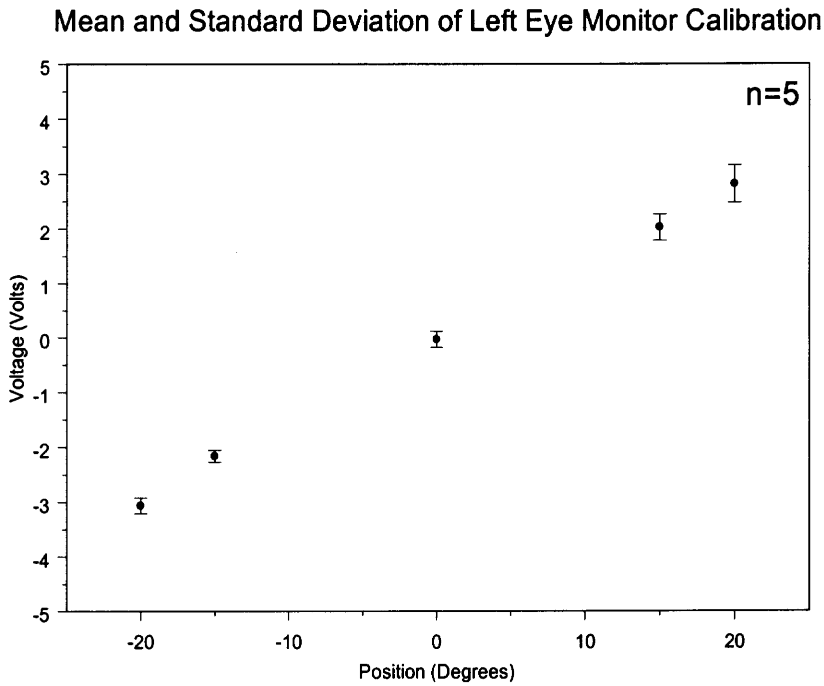

Figure 4.7 Mean results eye movement tracker calibration using stimuli on a computer monitor as targets for the left eye.

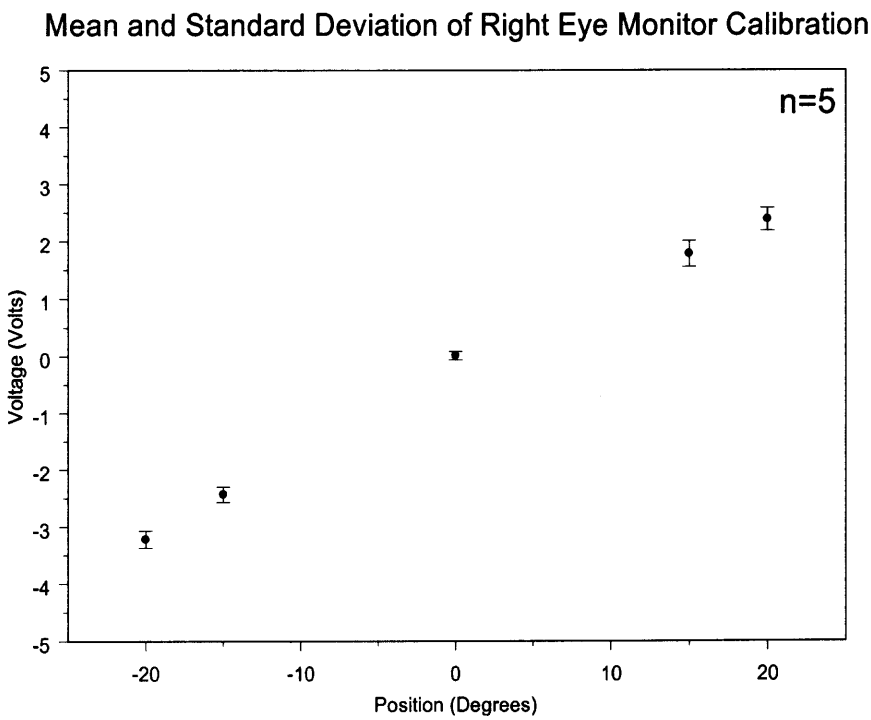

Figure 4.8 Average results eye movement tracker calibration using stimuli on a computer monitor as targets for the left eye.

4.2 Monitor versus Oscilloscope Display in Smooth Pursuit Results

Shown below are examples of latency during the first second of eye movement data taken from the same trials analyzed for periodicity, involving presentation of a vertical line oscillating at 0.2 Hz for two periods in ten seconds on the oscilloscope and the computer monitor. In all latency graphs, the combined stimulus is denoted in pink while the combined eye movement response (the sum of left eye and right eye) is shown in green.

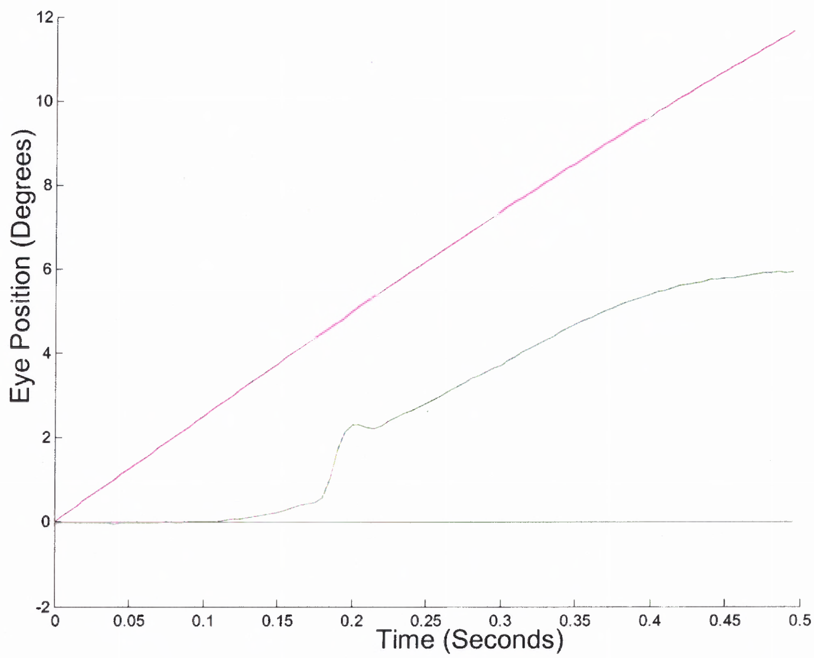

Figure 4.9 An example of the first half-second of eye movement data for latency analysis sampled at 200 Hz using an oscilloscope for stimulus presentation.

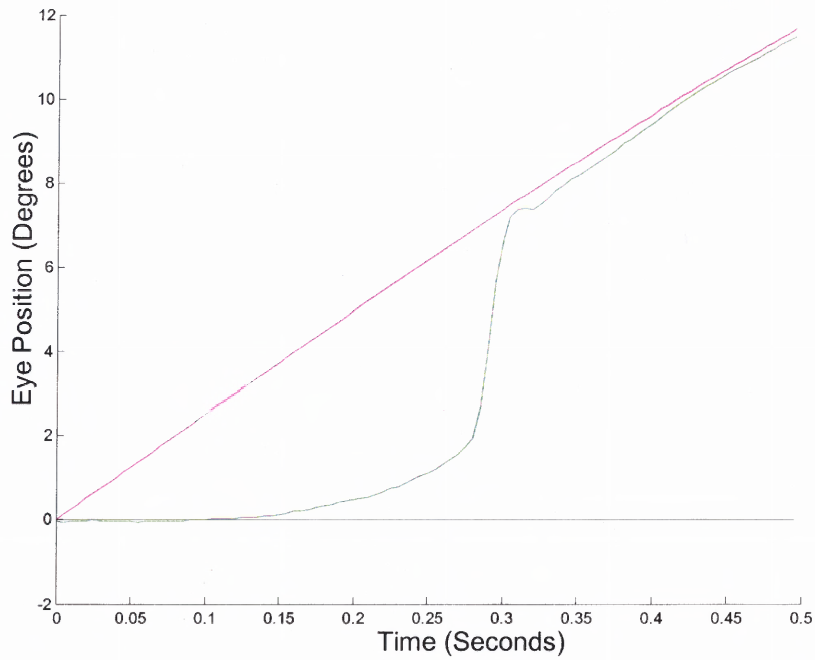

Figure 4.10 A graph of the first half-second of eye movement data for latency analysis sampled at 200 Hz using a monitor display for stimulus presentation.

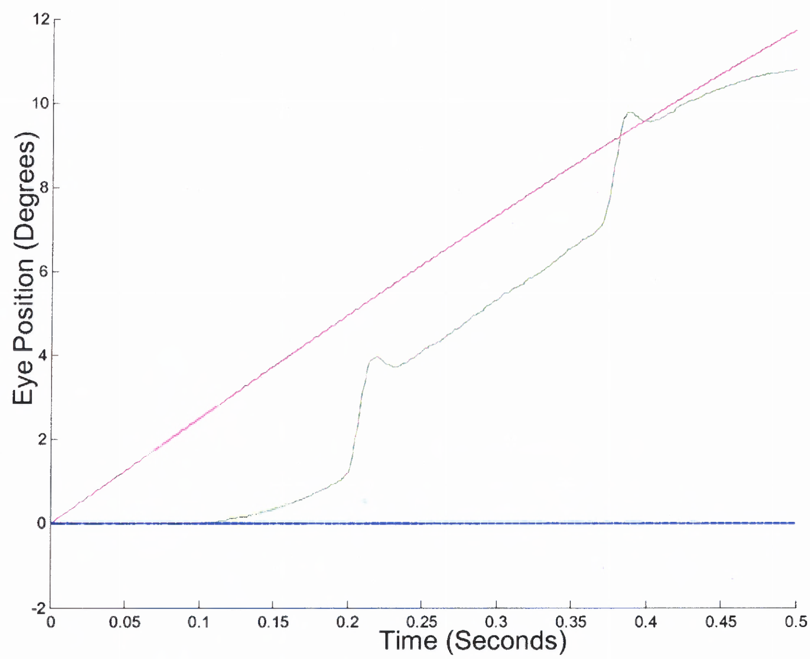

Figure 4.11 An example of the first half-second of eye movement data for latency analysis sampled at 1000 Hz using a monitor display for stimulus presentation.

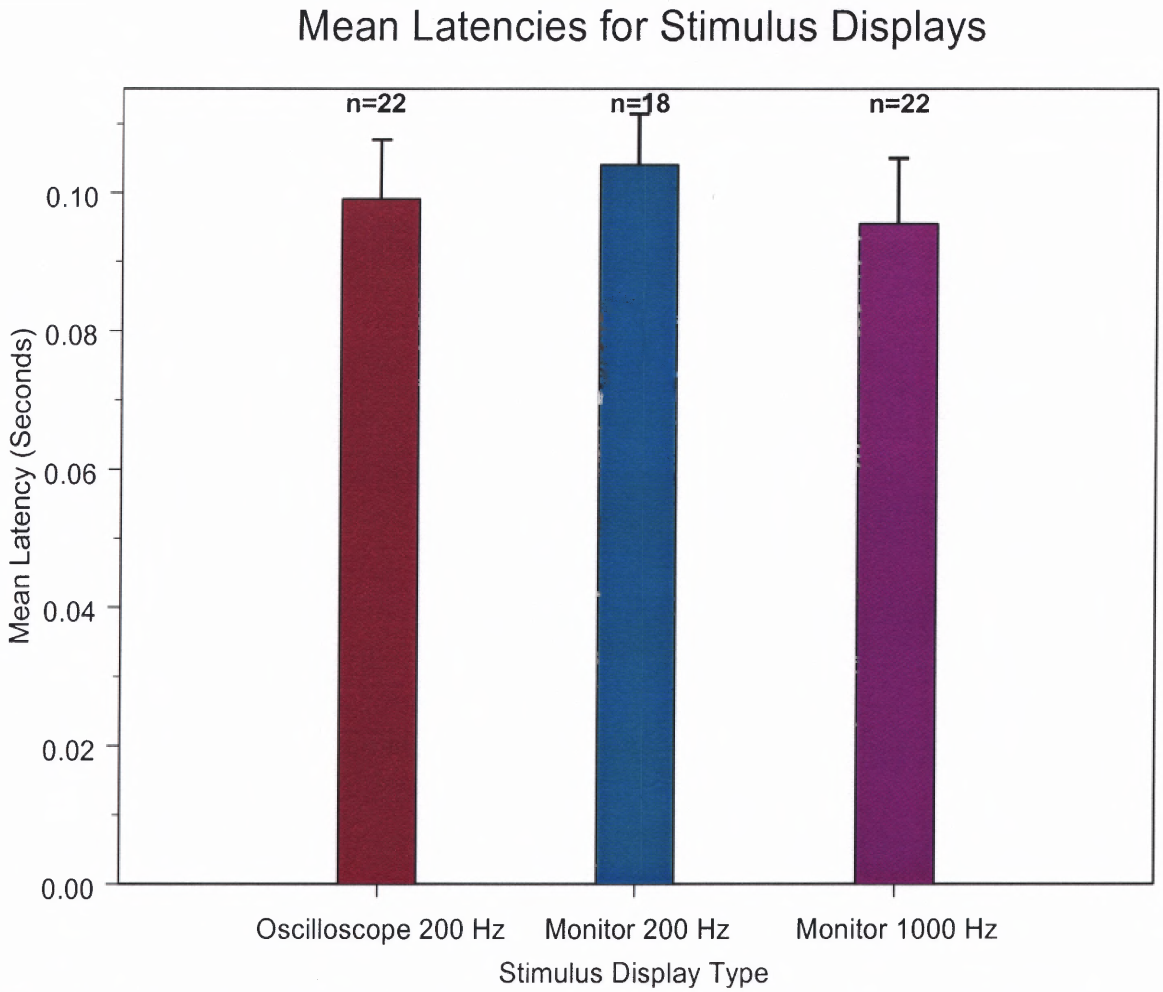

Figure 4.12 Mean smooth pursuit latencies for stimulus displays on: the oscilloscope with eye movement data sampled at 200 Hz, the computer monitor with eye movement data sampled at 200 Hz, and the computer monitor with eye movement data sampled at 1000 Hz.

Smooth pursuit latencies for eye movements sampled at 200 Hz from a stimulus on the oscilloscope screen range from 92.1 to 109.5 milliseconds, while latencies sampled at 200 Hz from a stimulus on the computer monitor range from 88.0 to 114.9 milliseconds. Latencies for eye movements sampled at 1000 Hz from a stimulus displayed on a computer monitor range from 77.3 to 110.8 milliseconds.

A t-test for a comparison of means of latency data from an oscilloscope with eye response sampled at 200 Hz and that from a monitor with eye response sampled at the same rate yields a p-value of 0.0645. A t-test for a comparison of means of latency data from an oscilloscope with eye response sampled at 200 Hz versus that from a monitor with eye response sampled at 1000 Hz yields a p-value of 0.2096.

Table 4.3 Mean Latencies and Standard Deviations for Stimulus Display on the Oscilloscope (Control) and the Computer Monitor (Test)

	Oscilloscope 200 Hz (control)	Computer Monitor 200 Hz (experiment)	Computer Monitor 1000 Hz (experiment)
Mean Latency (seconds)	0.0990	0.1040	0.0955
Standard Deviation	0.0068	0.0074	0.0096

Below are examples of eye movement data from control and experimental apparati. Each graph shows a complete experimental trial lasting ten seconds in duration where a subject attempted to pursue a vertical line stimulus oscillating at 0.2 Hz for two periods between +10 degrees and -10 degrees. In each plot, the left eye response is denoted in red, the right eye response is in blue, the combined response of the sum of left eye and right eye is in green, and the combined stimulus is in pink.

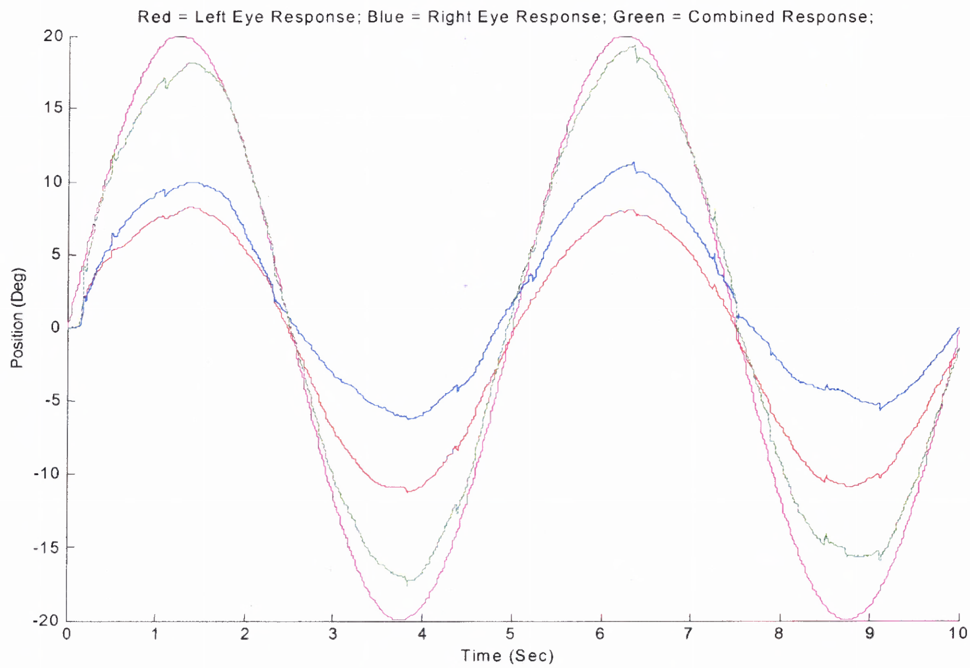

Figure 4.13 An illustration of eye movement data sampled at 200 Hz using an oscilloscope for stimulus presentation.

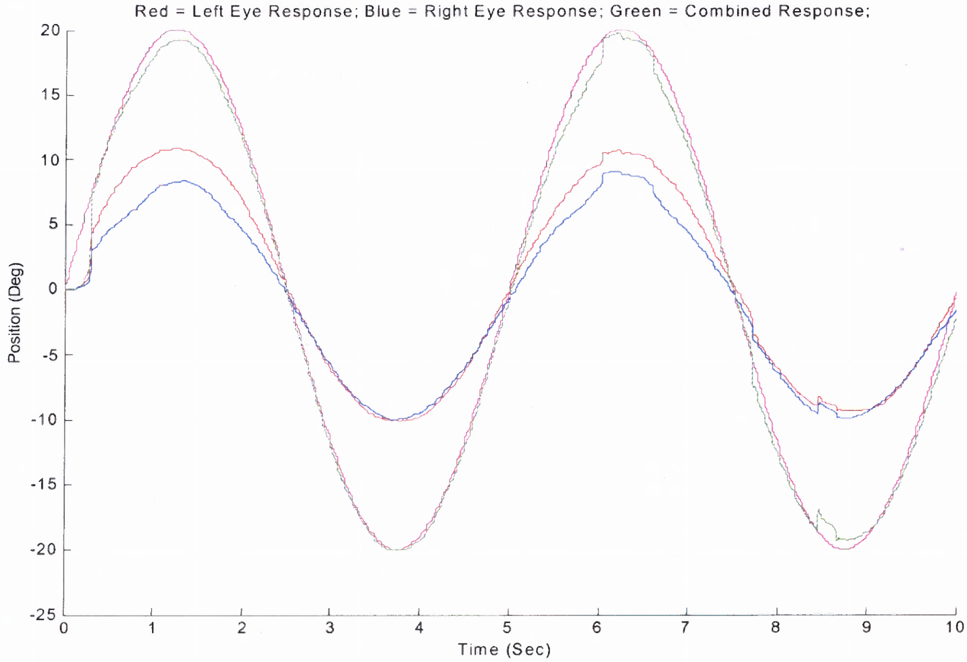

Figure 4.14 An example of eye movement data sampled at 200 Hz using a monitor display for stimulus presentation.

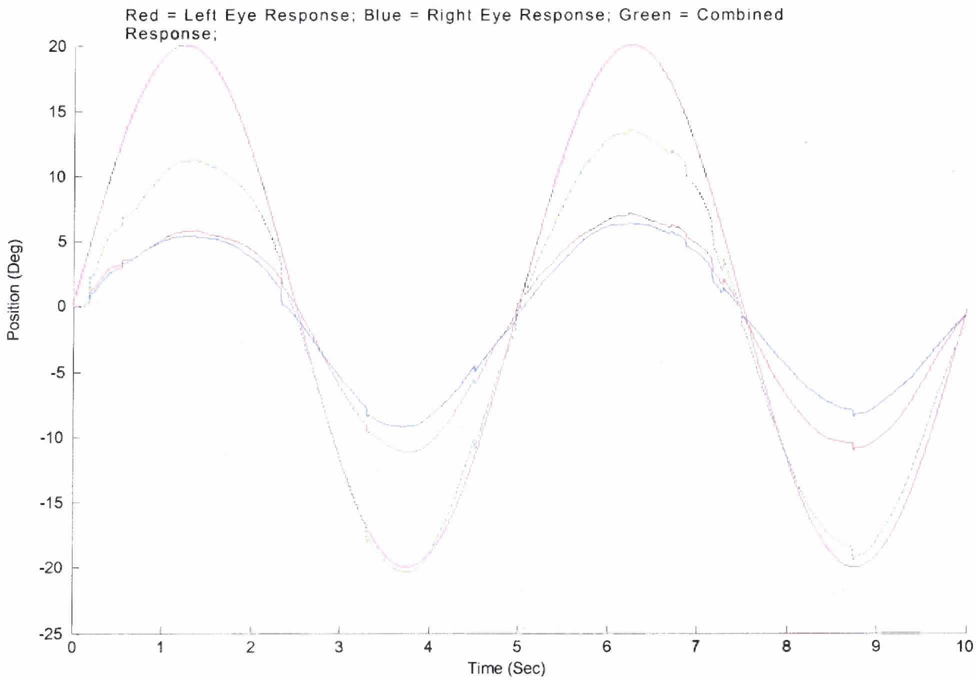

Figure 4.15 An image of eye movement data sampled at 1000 Hz using a monitor display for stimulus presentation.

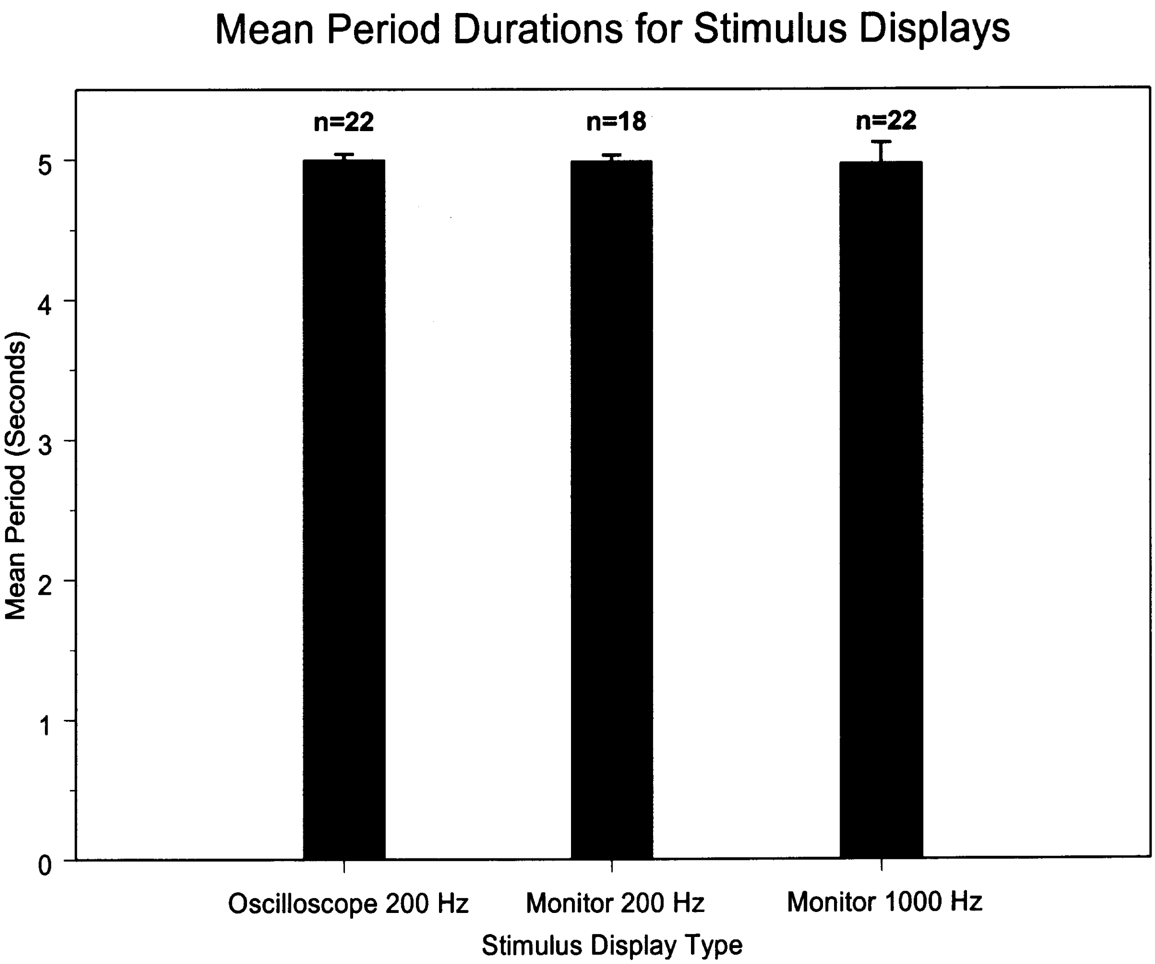

Figure 4.16 Mean smooth pursuit period durations for stimulus displays on: the oscilloscope with eye movement data sampled at 200 Hz, the computer monitor with eye movement data sampled at 200 Hz, and the computer monitor with eye movement data sampled at 1000 Hz.

Smooth pursuit period durations for eye movements sampled at 200 Hz from a stimulus on the oscilloscope screen range from 4.9194 to 5.0806 seconds, while latencies sampled at 200 Hz from a stimulus on the computer monitor range from 4.9194 to 5.0538 seconds. Latencies for eye movements sampled at 1000 Hz from a stimulus displayed on a computer monitor range from 4.4624 to 5.2688 milliseconds

Table 4.4 Mean Period Durations and Standard Deviations for Stimulus Display on the Oscilloscope (Control) with Eye Movement Data Sampled at 200 Hz and Monitor (Experiment) with Eye Movement Data Sampled at 1000 Hz

	Oscilloscope 200 Hz (control)	Computer Monitor 200 Hz (experiment)	Computer Monitor 1000 Hz (experiment)
Mean Period (seconds)	4.9948	4.9836	4.9694
Standard Deviation	0.0447	0.0471	0.1496

A t-test for a comparison of means of periodicity data from an oscilloscope with eye response sampled at 200 Hz and that from a monitor with eye response sampled at the same rate yields a p-value of 0.4472. A t-test for a comparison of means of periodicity data from an oscilloscope with eye response sampled at 200 Hz versus that from a monitor with eye response sampled at 1000 Hz yields a p-value of 0.4592.

CHAPTER 5

DISCUSSION

Data analysis of results from *Monitor versus Light-Emitting Diode Calibration* demonstrated that monitor display of calibration targets is virtually equivalent to LED display of calibration targets as R^2 values from the both apparati are comparable to the hundredths place for targets placed for ± 20, ± 15, and 0 degrees of eye movement. Discrepancies in voltage data do not occur until the thousandths place. These differences may be most likely due to the resolutions of the data acquisition card and/or the eye movement monitor. In other words, the differences are within the normal error of the system. A wider monitor placed farther from the subject may have reduced inconsistencies between monitor and LED calibration data, but appears unnecessary for such minor data discrepancies.

Targets consisting of LEDs can be placed in a wider scope of space than those on a monitor but for the intended purposes of this instrumentation, the maximum range of targets that can be shown on a monitor is appropriate for the capabilities of the Skalar Limbus Tracker. The results from this experiment confirm that computer monitors can be used in horizontal eye movement experiments in the range of ± 20 degree eye movements from midline.

Qualitative analysis of ten seconds of eye movement data from *Monitor versus Oscilloscope Display in Smooth Pursuit* are generally comparable to Figure 1.6b in which a subject was also presented with a slowly moving stimulus, as eye movements remain in-phase with the stimulus after an initial saccade. The maintenance of close fixation of eye movement to stimulus movement while producing involuntary smooth movement in oscilloscope and computer monitor displays verify the use of monitors for pursuit stimulus display on a qualitative basis.

Eye movement data sampled at 1000 Hz shows nearly the same detail as those sampled at 200 Hz. A faster moving stimulus may have elicited additional saccades, which commonly occur at speeds of 100 to 900 degrees per second. Saccades would have appeared as sharper responses, with faster dynamics containing response with greater peak velocities when sampled at 1000 Hz rather than 200 Hz, emphasizing the effect of different sampling rates on data quality.

Pursuit latency is the amount of time that a moving target must be present in the field of vision before smooth pursuit begins. Quantitative latency analysis of results from *Monitor versus Oscilloscope Display in Smooth Pursuit* revealed ranges of smooth pursuit latencies that complied with parameters defined by Yarbus (1967) and Lisberger and Westbrook (1985) of 80 to 130 milliseconds, and as short as 60 milliseconds for a small target. Since p-values among means of data from all apparati for latency are greater than the 0.05 threshold, the computer monitor can be considered *not different* from the oscilloscope in smooth pursuit stimulus display. Discrepancies in latency data between oscilloscope and computer monitor stimulus displays may be due to subject fatigue as well as biological variability. While there was the presence of loss of arc with the flat display screens of the oscilloscope and monitor, values of error per eye were the same since each display was placed at an equal distance of 22 cm from the subject.

Quantitative periodicity analysis demonstrated mean experimental values within 3.5 and 5 milliseconds from the control data set. As p-values among means of data from all apparati are substantially greater than the 0.05 threshold, the computer monitor can be considered equivalent to the oscilloscope in smooth pursuit stimulus display. Period durations less than five seconds may be attributed to subject prediction of stimulus behavior. Prediction can be eliminated in future experiments by presenting the subject with a stimulus of a different frequency and/or range of movement for each trial.

In terms of timing accuracy, the BK Precision® 2120B Dual Trace Oscilloscope displayed stimuli accurately within ±3 % (BK Precision® Corporation, 2000) while the computer monitor displayed stimuli within ±0.08% accuracy, as timing was off by as much as ±4 milliseconds for a 5000 millisecond period within a trial.

In regard to visual properties of the stimulus, the entire oscilloscope screen appeared to be slightly illuminated during stimulus presentation, which may have been a distraction from the stimulus. On the computer monitor, sweep of the oscillating line left a faint trail on the screen the same color as the stimulus. Adjusting the brightness and/or contrast of the monitor alleviated this problem.

CHAPTER 6

CONCLUSION

The goal of this thesis was to develop a stimulus display that offered more features and removed limitations of existing systems of LEDs and oscilloscopes. The LED system was incapable of presenting smooth pursuit stimuli. The existing oscilloscope system was unable to present stimuli beyond: ± 10 degrees, a single line, one color and ± 3 percent timing accuracy. The new system possesses the following new features, which make it a superior solution compared to the previous equipment:

1. Greater range;
2. Additional colors;
3. Variation of stimulus shapes and sizes;
4. Increased timing accuracy;
5. Theorized IPD accountability;

The new system had to perform with two key factors present in the previous stimulus display, which are flicker prevention and timing accuracy. After investigating and developing three solutions to solves this problem, it was determined that drawing an image and then overdrawing the previous image while simultaneously drawing the new image resulted in the optimal engineering solution. Validation results proved that the new solution produced the same results as the previous solution while adding several new features. Furthermore, the computer architecture allows the flexibility for additional stimulus types in the future.

CHAPTER 7

FUTURE RESEARCH

Yarbus found that a real target versus an imaginary target is necessary for smooth eye movements (1967). Churcher and Heywood determined that an afterimage can be used as a target, as they proved that subjects were consistently able to make smooth eye movements by tracking an oscillating afterimage target (1971). In tracking an imaginary oscillating target, subjects repeatedly failed to produce smooth eye movements, and instead made saccades interspersed with fixations, creating a series of "staircases". Given these facts, an objective method of measuring foveal positive afterimage (PAI) latency by tracking eye movement behavior over time can and will be studied. Data analysis involves differentiating sustained smooth movement behavior from highly saccadic/fixational behavior over time by using known ranges of saccadic velocity from previous empirical studies. Results expected are:

1. Less-saccadic smooth-pursuit eye movements for the duration of positive afterimage followed by more saccadic and fixational eye movements during positive afterimage decay, negative afterimage, decay, and absence;
2. Objective quantification of afterimage duration in general agreement with previous light stimulus intensity/duration versus afterimage duration relationships;

Performing this study may reveal more objective values for efficient lighting, in terms of intensity, duration, and safety that produces the longest afterimage. This can be applied to develop more reliable flash devices for military applications.

This experiment may also reveal, more objectively, ideal brightness levels of lighting that do not cause an afterimage as bright constant lighting as visual clues is necessary to guide pilots in landing. However landing aircraft during night operations may result in accidents and fatalities due to spatial disorientation induced by afterimages (Schmidt, 1999). Thus, in terms of reducing spatial disorientation from afterimages, precise safety standards for lighting are necessary.

Attempting an objective method for measuring positive afterimage demands less of subjects and makes extensive analysis of subjective data unnecessary. In employment of an objective method for measuring afterimage latency, perceptive stimuli like sound may be introduced to an experiment to measure its effect on afterimage duration.

Further development of monitor display stimuli in Vision Research Program 3.0 includes more complex image presentation and animation. Alvarez has proposed presenting subjects with a stationary stimulus whose size varies during an experimental trial in an attempt to trigger the vergence oculomotor system (personal communication, April 2003).

APPENDIX A

TRIGGER CONFIGURATION

At the beginning of *Vision Research Program Version 1.0* the channel connecting the trigger to the National Instruments data acquisition board model 6024e was initialized using a LabVIEW virtual instrument (VI) block called *AI Config.vi* (Figure 2.6). It was set to read from channel 2 on port 0. AI Config.vi relayed this information to *AI Start.vi* which was configured the number of scans to be read to five from trigger type of *digital A* at the rate of 1000 scans per second (Figure A.1). Found empirically, five was the least amount of scans that maintained the highest program stability. Shown in Figure A.2, a while loop which exits while its contents give a true value, kept iterating until *AI Read.vi* detected a trigger pull. A low trigger state returned a false value to AI Read.vi, and this was inverted to true. Once a high trigger state (trigger press) was detected, AI read scan in five "dummy" samples. Once all five scans were acquired, the program exited the while loop. At the end of the program, *AI Clear.vi* emptied the buffer to remove latent information (Figure A.3).

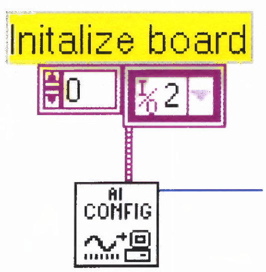

Figure A.1 AI Config block in LabVIEW configured for channel 2 on port 0.

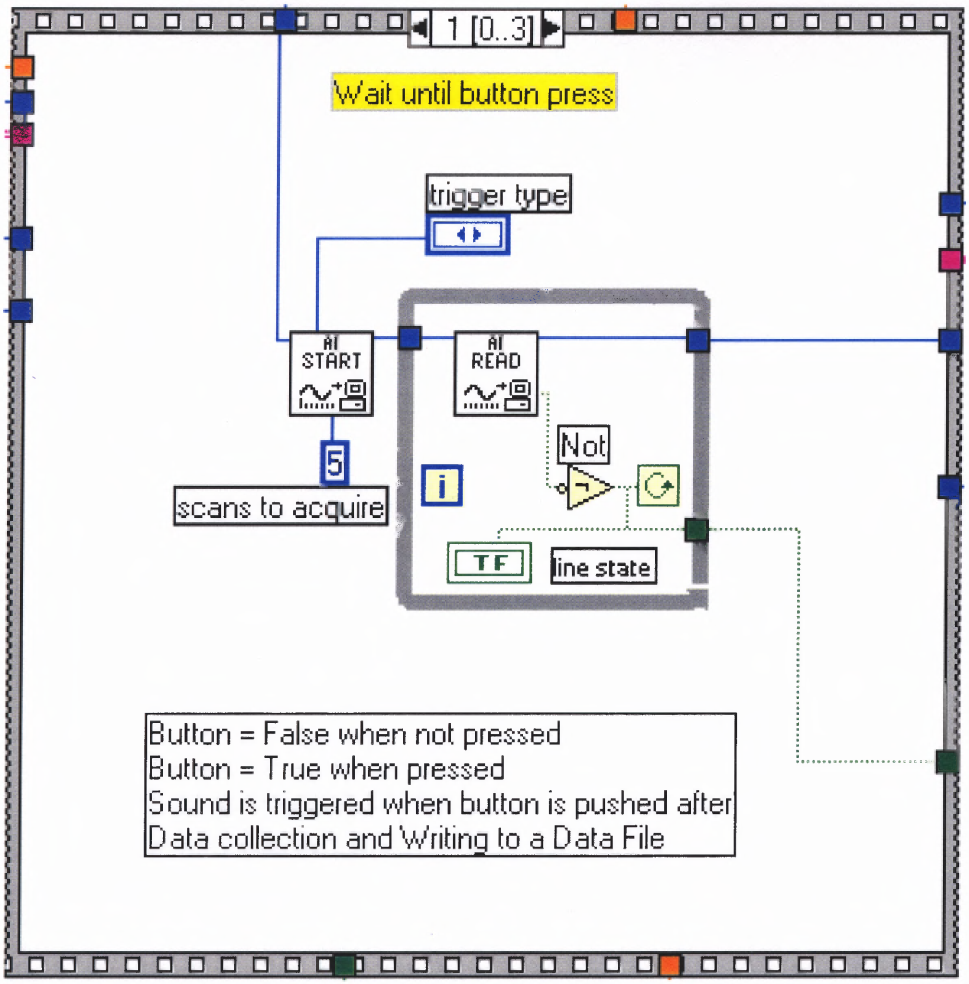

Figure A.2 AI Start.vi and AI Read.vis in LabVIEW.

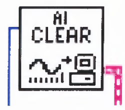

Figure A.3 AI Clear.vi in LabVIEW. AI Clear.vi empties the buffer at the end of the program.

APPENDIX B

TARGET PLACEMENT FOR HORIZONTAL EYE MOVEMENTS

B.1 Manual Calculation

Target A, of known distance from the subject is at midline. The horizontal distance of a second *Target B* from Target A is unknown. The desired amount of eye movement for both the left eye (LE) and right eye (RE) from Target A to Target B is *d* degrees. The distance from the subject to Target A is given as *D* centimeters. Inter-pupillary distance (IPD) is given and generally accepted as 6 centimeters.

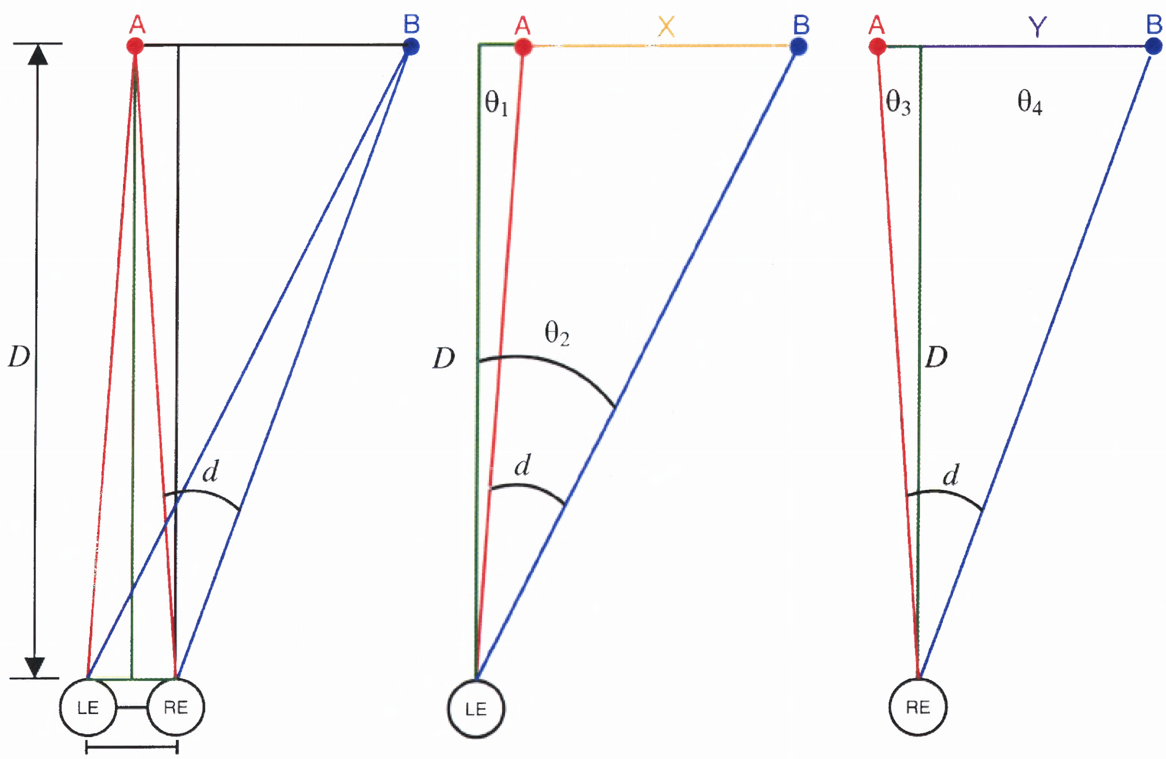

Figure B.1 Overhead schematic of targets A and B placed *D* centimeters from the subject.

To determine the placement of Target B in relation to Target A:

Left Eye (LE)

$$\theta_1 = \tan^{-1}\left(\frac{3cm}{D}\right)$$

$$\theta_2 = d + \theta_1$$

$$X + 3 = D \times \tan\theta_2$$

$$A \rightarrow B = X - 3cm$$

Right eye (RE)

$$\theta_3 = \tan^{-1}\left(\frac{3cm}{D}\right)$$

$$\theta_4 = d - \theta_3$$

$$Y = D \times \tan\theta_4$$

$$A \rightarrow B = Y + 3cm$$

Take the average of *A to B* for left eye and *A to B* for right eye to determine target placement.

B.2 Computer Calculation with Degrees to Pixels Virtual Instrument

Due to the frequent need to determine target placement on a computer monitor at a screen resolution of 1024 x 768 pixels, for desired degrees of eye movement when operating the modified program, a sub-virtual instrument (sub-VI) was developed in LabVIEW. Values such as distance from the subject to the target *(D)* was hard-coded as 40 cm for the first experiment, *Monitor versus Light-Emitting Diode Calibration*, then as 22 cm for the second- *Monitor versus Oscilloscope Display in Smooth Pursuit*. For future experiments this value will be a constant and not a variable because 40 cm is the optimal distance for the stimulus monitor. The center of the monitor screen was hardcoded as 512 pixels.

Inter-pupillary distance (IPD) is operator adjustable. Also, a conversion factor such as the pixels to millimeter (mm) value given by ViewSonic Corporation (2002) offered, was hardcoded as 1024 pixels to 310mm (31 cm). This sub-VI is easily modifiable for different monitor distances and IPDs. It is useful in tandem with the *Pixel to Degree Converter* sub-VI described in the next section in lieu of hand calculations for percent errors due to flat stimulus presentation screens.

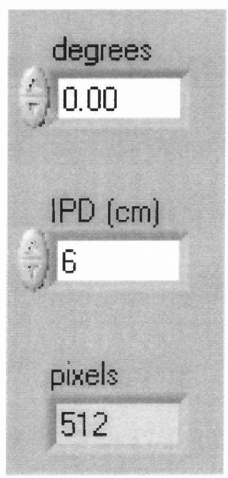

Figure B.2 The control panel of the *Degrees to Pixels* sub-VI.

Figure B.3 The icon for *Degrees to Pixels* sub-VI.

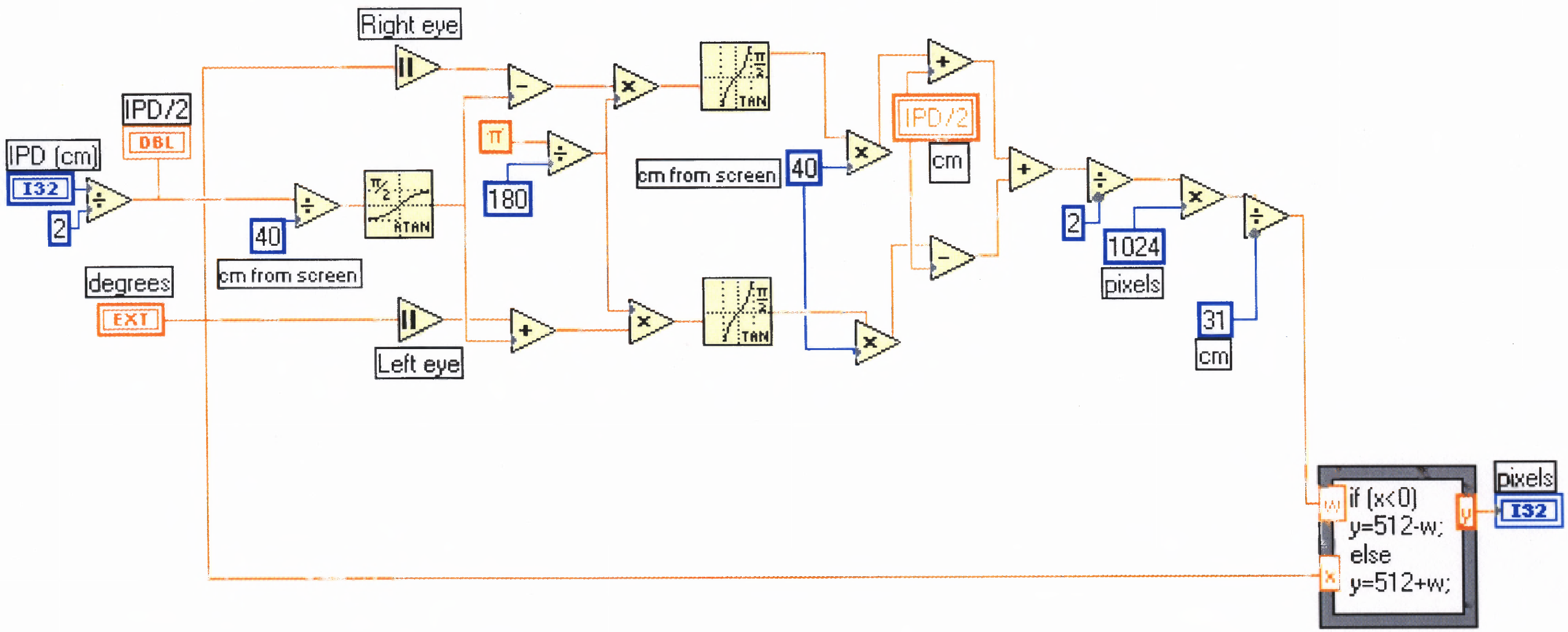

Figure B.4 Overview of the diagram of *Degrees to Pixels* sub-VI.

B.3 Pixels to Degrees Converter

Though the operator enters a degree value for desired stimulus target movement, this degree value was converted into number of pixels for the computer to understand. This sub-vi, originally intended for a method of data analysis, was developed to convert the number of pixels on the monitor to degrees of eye movement for both left eye and right eye, were they to move there. Using this in tandem with the sub-VI, *Degrees to Pixels* converter, described in *Appendix B.2*, the operator can calculate the percent of error of eye movement due to loss of arc for both eyes. The values *Pixels to Degrees Converter* output for both left and right eyes can each be subtracted from the actual desired angle of eye movement, then divided by that number to determine percents of error.

Constants and parameters are described in *Appendix Section B.2*.

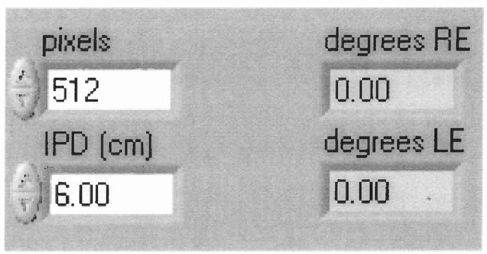

Figure B.5 Control panel of *Pixels to Degrees Converter* sub-VI.

Figure B.6 Icon of *Pixels to Degrees Converter* sub-VI.

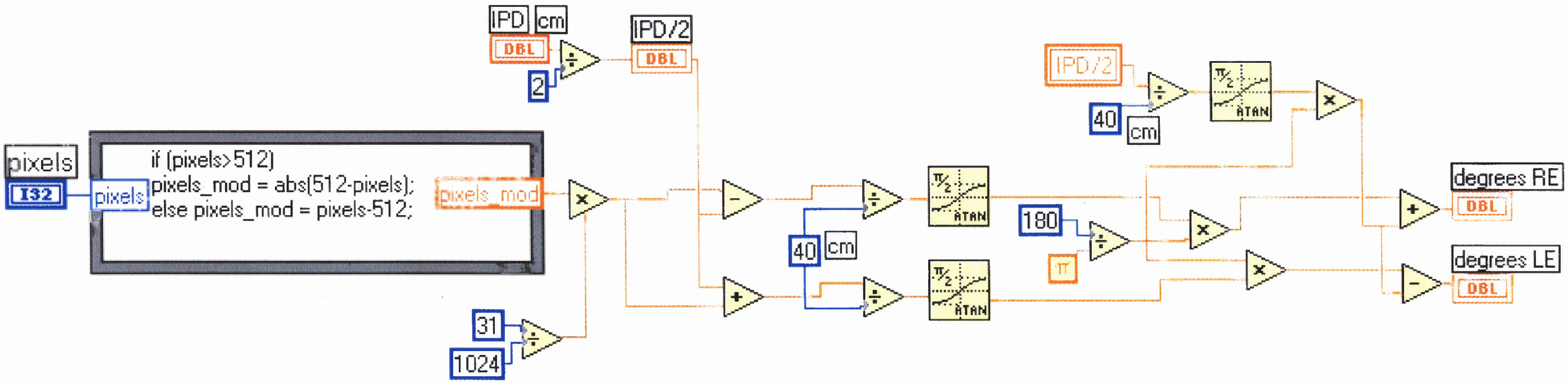

Figure B.7 Overview of the diagram of *Pixels to Degrees Converter* sub-VI.

REFERENCES

Alvarez, T. L., Chua, F. B., Daftari, A. P., DeMarco, R. M., Herrera, L., Bergen, M. T., *Vision Research Program 2.0*, Jan. 2003.

Alvarez, T. L., Bergen, M. T., Gupta, R., *Vision Research Program 1.0*, Jun. 2002.

Alvarez, T. L. "Class 4 Stereo Vision – Computational Brain", *Neural Engineering, Eye Movements Lecture,* Jul. 2001.

Alvarez, T. L., *Vision Data Analysis Program 2.0*, 1998, 2003.

Daftari, A. P., *Five-Point Calibration for Vision Research Program 2.0 (Alvarez, et al., 2003)*, Jan. 2003.

BK Precision® Corporation, *Instruction Manual for BK Precision® Models 2120B and 2125A 30 MHz Dual Trace Oscilloscopes*, Placentia, California, 2000.

Buttner-Ennever, J. A, Buttner, U., Neuroanatomy of the ocular motor pathways", *Baillieres Clinical Neurology*, vol. 1(2), pp. 263-87 Aug. 1992.

Cambridge Research Systems, Inc. (1999), *Skalar IRIS IR Light Eye Tracker*, Retrieved November 24, 2002 from: http://www.crsltd.com/catalog/skalar/iris/.

Churcher, J., Heywood, S., "Eye movements and the afterimage- I. tracking the afterimage", *Vision Research*, vol. 11, pp. 1163-1168, Mar. 1971.

Churchland, P. S., Sejnowkski, T. J., *The Computational Brain*, Massachusetts Institute of Technology, 1999.

Coren, S., Ward, L. W., *Sensation and Perception*, Harcourt Brace Jovanovich, San Diego, California, 1989.

GraphPad Software Inc., (2002), *GraphPad QuickCalcs: Analyze continuous data*, retrieved May 1, 2003 from http://www.graphpad.com/quickcalcs/ContMenu.cfm.

Herrera, L. *Oscilloscope Sine Wave Stimulus for the Vision Research Program 2.0*, Jan. 2003.

Hodgson, T. L., "The location marker effect. Saccadic latency increases with target eccentricity," *Experimental Brain Research*, vol. 145(Churcher et al., 1971), pp. 539-542, Aug. 2002.

Krauzlis, R. J., Miles, F. A., Zivotofsky, A. Z., "Target selection for pursuit and saccadic eye movements in humans", *Journal of Cognitive Neuroscience*, vol. 11 (Matrox Graphics, Inc., 2003), pp. 641-649, 1999.

Leigh, R. J., Zee, D. S., *The Neurology of Eye Movements*, F.A. Davis Company, Philadelphia, 1991.

Lisberger, S. G., Evinger, C., Johanson, G. W., Fuchs, A. F., "Relationship between eye acceleration and retinal image velocity during foveal smooth pursuit eye movements in the man and monkey", *Journal of Neurophysiology*, vol. 46, pp. 229-249, 1981.

Lisberger, S. G., Westbrook, L. E., "Properties of visual inputs that initiate horizontal smooth pursuit eye movements in monkeys", *Journal of Neuroscience*, vol. 5, pp. 1662-1673, 1985.

Lisberger, S. G., Morris, E. J., Tychsen, L., "Visual Motion Processing and Sensory-Motor Integration for Smooth Pursuit Eye Movements," *Annual Review of Neuroscience*, vol. 10, pp.97-129, 1987.

Martini, F. H., *Fundamentals of Anatomy and Physiology*, Prentice Hall, Upper Saddle River, NJ 07458, 1998.

MathWorks, Inc., (2003), *MatLAB® 6.5: The Language of Technical Computing*, Retrieved January 21, 2003 from: http://www.mathworks.com/products/MatLAB/.

Matrox Graphics, Inc. (2003), *Matrox G200 Multi-Monitor Series*, Retrieved January 21, 2003 from: http://www.matrox.com/mga/products/g200_mms/home.cfm.

Meyer, C. H., Lasker, A. G., Robinson, D. A., "The Upper Limit of Smooth Pursuit Velocity," *Vision Research*, vol. 25, pp. 561-563, 1985.

National Instruments Corporation (2003), *BNC-2090*, retrieved April 14, 2003 from http://sine.ni.com/apps/we/nioc.vp?cid=1177&lang=US.

Robinson, D. A., "The mechanics of human smooth pursuit eye movements", Journal of Physiology, vol. 180, pp. 569-591, 1965.

Schmidt, R. T., "Reduce risk of inducing spatial disorientation using physiologically compatible ground lighting", *Aviation, Space, and Environmental Medicine*, vol. 70(6), pp. 598-603, Jun. 1999.

Semmlow, J. L., *Vision Data Analysis Program Version 1.0*, 1995.

Stark, L., Vossius, G., Young, L. R., "Predictive control of eye tracking movements", *IRE Transactions on Human Factors in Electronics*, vol.3, pp. 52-56, 1962.

ViewSonic Corporation (2002), *ViewSonic E70fb*, retrieved January 21, 2003 from http://www.viewsonic.com/products/crt_e70fb.htm.

Yarbus, A. E., *Eye Movements and Vision*, New York: Plenum Press, 1967.

Young, L. R., Sheena, D., "Eye-Movement Measurement Techniques," *American Psychologist*, pp. 315-330, Mar. 1975.