

EyeLink[®] II User Manual

Version 2.14



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Mississauga, Ontario, Canada

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Read instructions before use.

Type BF equipment (applied parts):
Metal parts connected to chassis of computer may contact user. Compliance with 601-1 medical equipment standards requires use of a medical grade power supply.



Entela Safety Mark: Compliance of this product with UL 2601-1, CSA C22.2 N0.601.1 and IEC 60601-1 is certified by Entela, an independent testing body.

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1. Introduction

1.1 EyeLink® II System Overview

Video-based eye tracking systems have long been acknowledged as simple to set up and operate. Early prototypes had a reputation for low data rates, poor spatial resolution, high noise, and frequent loss of data. EyeLink technology changed all of this in the early 1990s with custom-built high-speed cameras and hyperacuity image processing. Today, the EyeLink II has the highest resolution (noise-limited at $<0.01^\circ$) and fastest data rate (500 samples per second) of any head-mounted, video-based eye tracker. This exceptional data quality results in very low velocity noise, making the EyeLink II ideal for saccade analysis and smooth pursuit studies. On-line gaze position data can be detected by an external stimulus display computer (the Display PC) with digital delays below 3 milliseconds on average (with high stability at 1.11 ms SD), allowing the system to capably support gaze-contingent display applications. In addition, on-line data parsing occurs in real-time, making eye events such as saccade onset and landing, fixation start and end, and blinks available to a Display PC within 25 ms of their occurrence.

The EyeLink II system consists of three miniature cameras mounted on a comfortable padded headband. One head-tracking camera is used to detect infrared markers in the world, while two eye cameras focus on the left and right eyes respectively. An optional scene camera allows eye movement recordings to be integrated into the world-view of the subject in scene-camera mode.

The headgear was designed to be lightweight with a low center of mass for stability and minimal rotational inertia, all of which contribute to subject comfort while lowering fatigue. No mirrors are used in the EyeLink II system, making it robust, easy to set up, and without an artificial obstacle blocking the viewing area. Two eye cameras allow binocular eye tracking or easy selection of the subject's dominant eye without any mechanical reconfiguration required. Each camera has built-in infrared illuminators, digitally corrected for evenly distributed lighting of the entire field of view. Together with digital compensation for changes in ambient lighting, this results in exceptionally stable pupil acquisition.

The head-tracking camera integrated into the headband captures the positions of infrared illuminators placed at known locations in the world. This allows accurate tracking of the subject's point of gaze while allowing natural head motion and speech. The extremely low noise level of this optical tracker means that the noise level of computed gaze position data is comparable to that of the original eye position data, allowing gaze data to be used for saccadic analysis. In contrast, magnetic head trackers used in some head-mounted eye tracking

systems have high angular noise and therefore limit the usability of gaze position data.

The EyeLink II adds the ability to use corneal reflections in combination with pupil tracking (at 250 Hz), resulting in more stable tracking of eye position by reducing the errors caused by headband slippage, muscle tremor, or environmental vibration. Pupil-only tracking is available (at 250 or 500 Hz) if corneal reflection tracking is not possible, and relies on the stability of the EyeLink headband. The original EyeLink I head-mounted system used pupil-only tracking with great success.

Compatibility with a wide range of subjects is an outstanding feature of EyeLink II. Dark pupil tracking and off-axis illumination allow tracking of subjects with most eyeglasses, eliminating the bright reflections that can be problematic for many eye trackers. Eye camera sensitivity is high enough that even eyeglasses with heavy anti-reflection coatings that block up to 80% of infrared illumination are not a problem. Note that the corneal reflection tracking of the EyeLink II system is also usable with some eyeglasses but will be more limiting than the pupil only mode.

One of the outstanding innovations of the original EyeLink was the integration of most eye tracking functions into one intelligent system (the Host PC), relieving the experimenter of the need to implement data collection, calibration, integration of head tracker data, and saccade and fixation analysis as separate steps in data analysis. The EyeLink II continues to integrate all of these into a single package, allowing the experimenter to focus on stimulus presentation and data analysis. Real-time monitoring of data collection is possible as experimenters can view the subject's gaze position overlaid on experiment graphics in real time, allowing validation of calibration accuracy before recording and monitoring of data quality during data collection.

SR Research is committed to developing EyeLink-based applications to support many eye-tracking research applications through its Experiment Builder and Data Viewer software products, and will continue to make available software-development tools for programming EyeLink-based experiments and for using the EyeLink II data-link and file formats. Be sure to check the [SR-support.com](http://www.sr-support.com) web site for the latest releases of all of our software and documentation, as well as for example applications and other support discussion and solutions.

Please join the support forums at <http://www.sr-support.com> for product and documentation updates, freely downloadable as they become available.

1.2 Supporting Documents

This document contains information on using the EyeLink II system; the Host PC application, subject setup and calibration, and the basics of running an experiment. Information on system safety, maintenance, and storage is also provided. Appendix A explains the use of analog outputs and digital inputs and outputs via a DT334 card, if purchased. The following additional documents are also available either on the installation CD that came with your system or freely downloadable from the SR-support.com website:

- i. [EyeLink II Head-Mounted Installation Guide](#) – Describes a standard EyeLink II system layout and environmental considerations as well as the process followed to install the EyeLink II hardware and software on both the Host and Display PCs.
- ii. [SR Research Experiment Builder User's Manual](#) – Documentation for the optional, fully-featured experiment delivery system that provides novices and experts alike, easy access to the advanced features of EyeLink eye trackers.
- iii. [EyeLink Data Viewer User's Manual](#) – Introduces the optional data analysis tool, EyeLink Data Viewer, which allows the displaying, filtering, extraction and manipulation of EyeLink EDF data.
- iv. [EyeLink II Scene Camera User Manual](#) and [SceneLink User Manual](#) – Provides an introduction to the EyeLink II Scene Camera in Standalone mode, or using SceneLink to orchestrate recording. The scene camera option allows gaze position to be superimposed on a real world scene video being captured from a head mounted scene camera.
- v. [EyeLink Gaze Overlay User Manual](#) – Describes use of the optional Gaze Overlay device to provide a PAL/NTSC composite or S-Video stream of real-time gaze position overlaid on video source such as computer output.
- vi. [EyeLink Programmers Guide](#) – Provides suggestions on how to program experiments with the EyeLink in C, including a review of all sample experiments provided for Windows. The guide details the EyeLink API.
- vii. [EyeLink EDF Access API](#) – Documents the API giving access to all aspects of the EDF binary data file.
- viii. [EyeLink II Head-Fixed Installation Guide](#) and [EyeLink II Head-Fixed User Manual](#) – Use the EyeLink II cameras from a fixed position. These guides provide information on configuring cameras to operate from a fixed position.

1.3 EyeLink II System Configuration

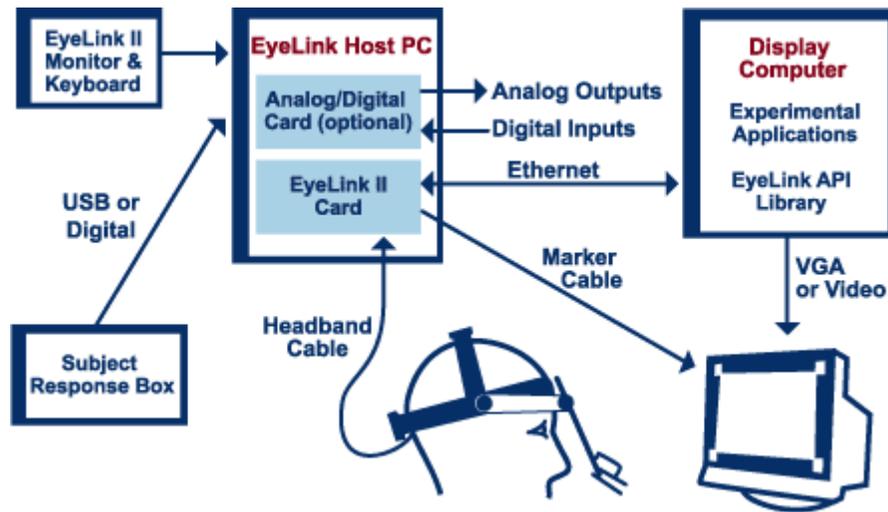


Figure 1-1: Typical EyeLink II System Configuration

1.3.1 EyeLink II Host PC

The EyeLink II Host PC performs real-time eye tracking at 250 or 500 samples per second, while also computing true gaze position on the Display PC monitor. On-line detection analysis of eye-motion events such as saccades and fixations is performed. All data can be stored in a data file on the Host PC, sent with minimal delay through the Ethernet link to the Display PC, or output as analog signals (if the analog/digital I/O card is installed). From the Host PC, the operator performs subject setup, monitors performance, and can interact with applications running on the Display PC. The Host PC:

- holds the EyeLink II high-speed eye tracking card, and optional analog output/digital input card.
- connects to the EyeLink II headband and powers four infrared markers (for head tracking) that are mounted on corners of Display PC's monitor.
- runs a special operating system to host the EyeLink II Host application. Your original operating system (such as Windows XP) is still available when not using the EyeLink II, if the included disk partitioning utility is used during installation.
- functions either as standalone eye tracker or interactively controlled by a Display PC connected through a 10BASE-T Ethernet cable.
- outputs data to hard disk or through optional analog output card.

- provides a millisecond accurate response box connected by a USB port.
- keyboard, display, and pointing device are used to control the eye tracker or as remote keyboard for Display PC applications.
- EyeLink II software integrates all needed eye tracking functionality, including subject setup, calibration, real-time data through an Ethernet link or optional analog output card, including recording data to hard disk.
- display has real-time feedback of eye data during calibration or recording, freeing the Display PC's monitor for calibration target and stimulus presentation.
- can be used as a regular computer when the eye tracker is not in use, for instance for data analysis purposes.

1.3.2 EyeLink II Display PC

The Display PC applications (supplied by the user or optionally acquired through SR Research) control experiment stimulus delivery and directs data collection on the Host PC. In cooperation with the Host PC, the Display PC presents calibration targets during eye-tracker calibrations, directs recording, can configure Host PC parameters, and has near real-time access to sample and event data across the Ethernet link.

SR Research's Experiment Builder software is specifically designed to facilitate the programming of EyeLink Experiments and runs on the Display PC. The Display PC can optionally be used for data analysis and processing.

Sample Display PC applications, C source code, and instructions for creating experiment applications are provided in the EyeLink II Windows developer kit included with every EyeLink system. MacOS X and Linux APIs are available from the support web site as are examples and information regarding third party software such as Psychtoolbox' EYELINKtoolbox, Presentation and E-Prime.

An appropriately programmed Display PC application:

- runs experiment software for control of the EyeLink II Host PC and performs stimulus presentation using the EyeLink API, allowing development of countless experimental paradigms.
- can configure and control the EyeLink tracker, and have access to real-time data including gaze position, response box button presses, and keyboard information.

- need only support display generation and control of the experiment sequence, while relying on the Host PC for creating the data file and reading the response box. This makes millisecond-accurate display timing possible, even under Windows.

1.3.3 EyeLink II Headband

The EyeLink II headband has two eye cameras for binocular tracking or instant selection of the eye to be tracked, a head-tracking camera with exceptionally low angular noise, and may optionally support a scene camera for recovering the subject's gaze position and world view. The headband is characterized by these key features:

- Off-axis illumination and high-contrast cameras for maximum compatibility with eyeglasses and contact lenses.
- Lightweight headband (~420g) has a low center of mass for stability, is well balanced and has low rotational inertia. This reduces neck muscle tremor and permits long periods of use without fatigue.
- Padded headband provides excellent grip on skin with low pressure, and is not affected by skin oils.
- No mirrors used for lightweight and robustness.
- All mechanical adjustments and sliding parts have been wear-tested to ensure long lifetime with no maintenance.

1.3.4 EyeLink II PCI Card

The EyeLink II PCI card performs the powerful image processing required to achieve the high temporal and spatial resolution of the system. The PCI card is hosted in the Host PC and has connectors for:

- EyeLink II headband on a 5 metre cable.
- Head tracking markers on a 7 metre cable.
- Ethernet cable for Display PC connection.

1.4 System Specifications

1.4.1 Tracking Modes

Mode	Sample Rate	Average Delay (Filter Off/On)	Noise (RMS)	Stability
Pupil Only	250 or 500Hz	3 ms / 5 ms / 7 ms	< 0.01°	Affected by headband slip and vibration
Pupil-Corneal Reflection (Pupil-CR mode)	250Hz	6ms / 10ms / 14 ms	< 0.022°	Good rejection of slip and vibration

1.4.2 Operational / Functional Specifications

Image Processing	Fully Digital
Pupil Tracking	Hyper acuity
Corneal Reflection Tracking	Hyper acuity, ultra low noise
Resolution (Gaze)	<0.005° (pupil and CR)
Velocity Noise	<0.5° average
Pupil Size Resolution	0.1% of diameter
Eye Tracking Range	±30° horizontal, ±20° vertical in pupil only mode.
Gaze Tracking Range	±20° horizontal, ±18° vertical
Head Tracking Distance	40-140cm (standard), -300 cm (Special markers)
Head Rotation Compensation Range	±15° for best accuracy, ±30° conditional on gaze angle
Head Position Compensation Range	Horizontal and vertical movements less than the width and height of display, and ±30% of the display-to-head distance at calibration
Built-in calibration, validation	Calibration / Validation using Pupil or Pupil-Corneal Reflection (pupil-CR) mode
Operating Environment	Tolerates significant indirect IR, pupil-CR mode can tolerate more headband slippage than pupil only mode
Subject Compatibility	Most eyeglasses and contact lenses do not present a problem in pupil only mode; still highly compatible in pupil-CR mode
Data File	EDF
EDF File and Link Data Types	Eye position, HREF position, gaze position, pupil size, buttons, messages, digital inputs
On-Line Eye Movement Analysis	Saccades, fixations, blinks, fixation updates
Real-Time Operator Feedback	Eye position cursor during calibration, validation, and recording. Camera images and tracking status.

1.4.3 Physical Specifications

EyeLink II Card	Half-length PCI (6.8"/176mm) long by 4.2" (107mm) high.
Headband	Padded, height and size adjustable.
Headband weight	~420 grams, low center of gravity
Headband cable length	4.2 metres
Eye camera distance	40 to 80 mm
Binocular Tracking	Standard
Eye Illumination	925 nm IR, IEC-825 Class 1, <1.2 mW/cm ²
Display Markers	900 nm IR, IEC-825 Class 1
Ethernet Link	TCP/IP or raw, 10BASE-T, built into EyeLink II card
Response box support	USB or digital
Analog output	Optional PCI card
Digital Control	Configurable
Host Operating system	ROMDOS operating system
Display Operating system API	Windows (95, 98, NT, 2000, XP), Macintosh.
Classification	Class II (grounding optional), type BF (conductive path from computer chassis to metal parts on the headband)
Power Supply Requirements	Powered from host computer power supply, 160W or greater power supply recommended. Medical-grade power supply is required for 601-1 compliance.
Operating conditions	15°C to 35°C, 20%-80% humidity (non-condensing), ambient pressure 101 kPa.
Storage conditions	-10°C to 40°C, 10%-90% humidity (non-condensing). Allow to warm to room temperature before unpacking or use after storage at temperatures below 10°C.
EyeLink II Card Power Requirements	+5V (2A), +12V (0.8A), -12V (0.2A), 22 watts
Electromagnetic compatibility and immunity 	FCC Part 15, Subpart B: Class A unintentional radiators (see statement below) CISPR 11:1997 and EN55011:1998 -- Class A, Group 1 ISM (Industrial, Scientific, and Medical) Equipment EN 60601-1-2:1993 – Part 1: General Requirements for Safety-Collateral Standard Electromagnetic Compatibility-Requirements and Tests.

NOTE: This equipment has been tested and found to comply with the limits for a Class A digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference when the equipment is operated in a commercial environment. This equipment generates, uses, and can radiate radio frequency energy and, if not installed and used in accordance with the instruction manual, may cause harmful interference to radio communications. Operation of this equipment in a residential area is likely to cause harmful interference in which case the user will be required to correct the interference at the users' expense.

WARNING: Changes or modifications not expressly approved by SR Research Ltd. could void the user's warranty and authority to operate the equipment.

2. EyeLink II Host Application Operation

2.1 Starting and Stopping the Host Application

To start the EyeLink II Host application, follow these simple steps:

- a) Start your Host PC
- b) If your system was installed with a boot manager, select the EyeLink II partition
- c) Type the following at the command prompt:

```
T [ENTER]
```

If the EyeLink II host application does not start then type the following at the command prompt.

```
cd EYELINK2\EXE [ENTER]
```

```
EYELINK2 [ENTER]
```

The EyeLink II Host Application should start and display the Offline tracker screen.

To stop the Host application press CTRL-ALT-Q together at any time on the Host PC keyboard. You may alternatively navigate to the Offline screen and click on the “Exit EyeLink” button. When the command line prompt is present, simply power off the Host PC.

2.2 Modes of Operation

The EyeLink II is a multipurpose, high resolution, real-time processing system. There are two unique primary operation modes:

Link Mode: In link mode, the eye tracker is partially controlled by the Display PC via the Ethernet link. The degree of Display PC control is dependent only on the display application itself. It is possible to have full control of the tracker via the Display PC; however this requires appropriate display application programming. A common scenario is to have the application on the Display PC initiate subject setup and calibration, while the operator uses the EyeLink II Host PC's keyboard to remotely interact with the application, perform drift correction, and handle problems if they occur.

Standalone Mode: In standalone mode, the eye tracker is an independent system, controlled by the operator by the Host PC tracker interface and keyboard. The Host PC may be connected to a display-generating computer for the purpose of displaying calibration targets only. Calibration is only required to use head-position compensation. There are two possible data output modes when running the EyeLink II as a standalone system. These output modes are not exclusive and include:

- a) Analog output. Using the optional analog output card, data is available in analog format. Analog output options are configurable via the “Set Options” screen and in the ANALOG.INI initialization file.
- b) File Output. Eye data is available in the EyeLink II EDF file format. This can be converted to an ACSII file format using the EDF2ASC.EXE conversion utility (or Visual EDF2ASC under Windows, MacOS X or Linux). File output options are configurable via the “Set Options” screen.

2.3 EyeLink II Host Application Navigation

The EyeLink II tracker interface consists of a set of setup and monitoring screens, which may be navigated by means of the Host PC mouse, key shortcuts, or from the Display PC application via link commands.

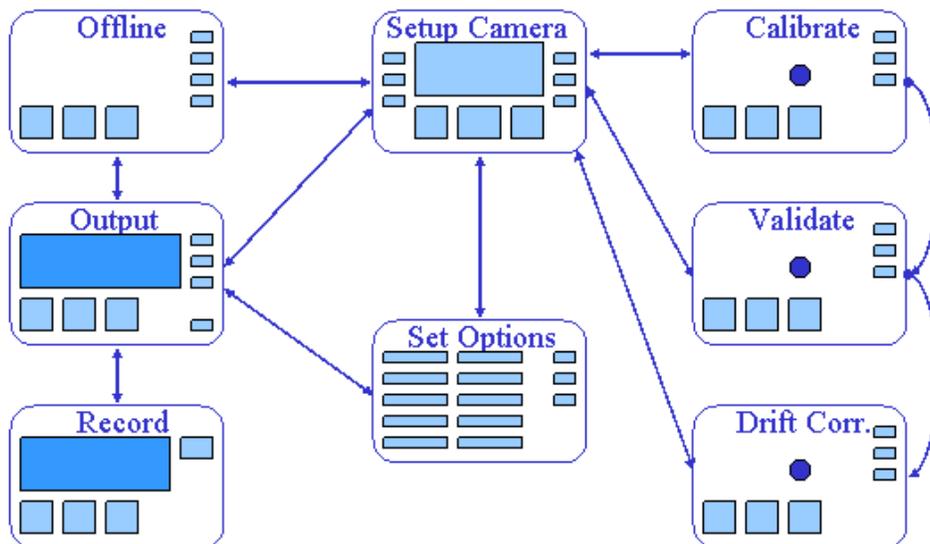


Figure 2-1: Screen Overview of EyeLink II Tracker Program

Each of the modes shown in the diagram above has a special purpose. Where possible, each screen has a distinctive appearance as shown in the figure. Screens with gray bars contain menus of key options for navigation and setup. Other screens have a key-navigation bar at the top of the screen and a status bar at the bottom. Arrows represent the navigations possible by keys, while any mode is accessible by way of the Ethernet link. Note the central role of the Setup menu: it serves as the mode control during subject setup.

The functions of each mode and the main access keys to other modes are summarized below. Pressing the on screen Help button or hitting the F1 key will open a screen sensitive Help menu listing all available key shortcuts for that screen. From any screen, the key combination 'CTRL+ALT+Q' will exit the EyeLink tracker program.

2.3.1 Offline Screen

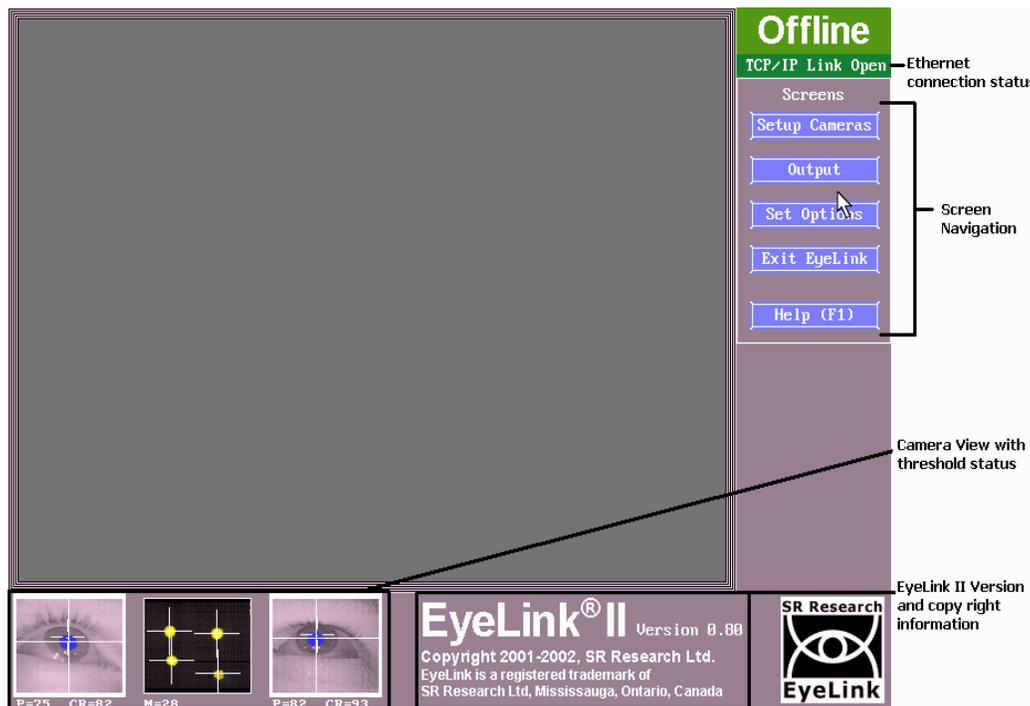


Figure 2-2 EyeLink II Offline Screen

2.3.1.1 Offline Screen Purpose

The off-line mode is the default start-up screen for EyeLink II. The main secondary screens can be accessed via the navigation buttons on the left hand side of the screen.

2.3.1.2 Offline Screen Main Functions

Setup Cameras	Click to go to the camera setup screen. Keyboard Shortcuts: ENTER = 'Camera Setup'
Output	Click to go to the 'Output' screen, from which you can start a manual recording session. Keyboard Shortcuts: O = go to 'Output' screen
Set Options	Click for access to a variety of system options and settings on the 'Set Options' screen. Keyboard Shortcuts: S = go to Set options
Exit EyeLink	Click to quit the EyeLink II Host PC application. Keyboard Shortcuts: Ctrl + Alt + Q = Exit EyeLink
Help (F1)	Click to access the on-line help page for the current screen. All available key shortcuts are listed on the Help screen. Keyboard Shortcuts: F1 = open Help screen

2.3.1.3 Offline Screen Key Shortcuts

ENTER	Go to the 'Camera Setup' screen
O	Go to the 'Output' screen
S	Go to the 'Set Options' screen
Ctrl + Alt + Q	Exit the EyeLink Host PC application
F1	View Help and keyboard shortcuts for the 'Offline' screen

2.3.2 Camera Setup Screen

2.3.2.1 Camera Setup Screen Purpose

This is the central screen for most EyeLink II setup functions. From this screen the eye and head tracking cameras can be set up, and their images can be thresholded. Eye(s) to be tracked, tracking mode and options can also be set. Calibration, Validation, and Drift correction are performed from this screen.

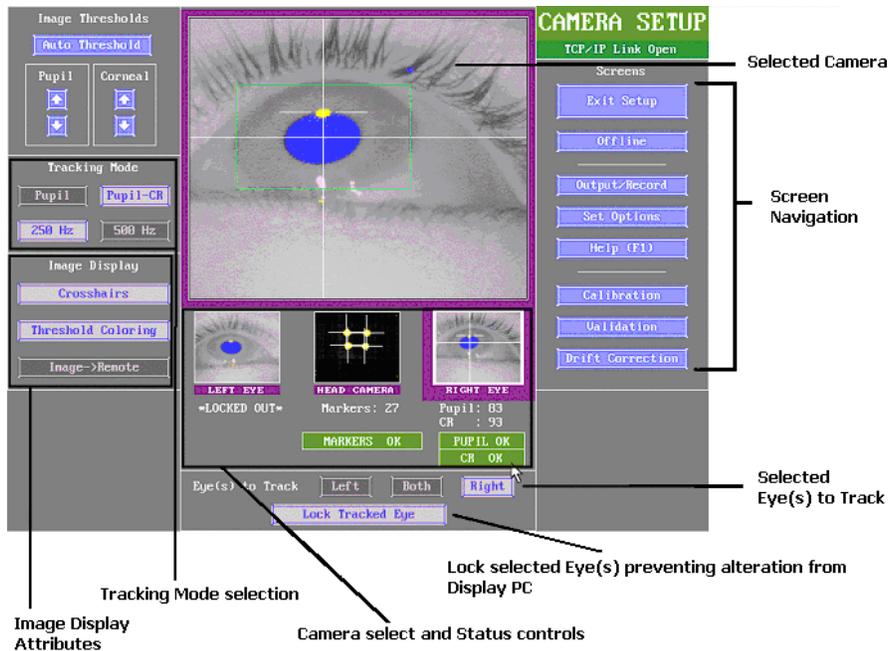
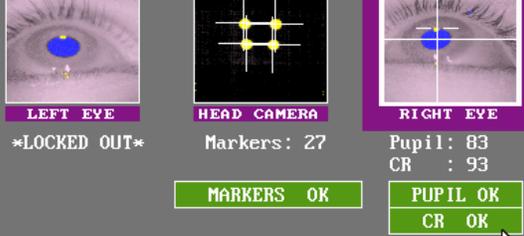


Figure 2-3 EyeLink II Camera Setup Screen

2.3.2.2 Camera Setup Screen Main Functions

	<p>Click to have the Host PC compute threshold levels automatically. In most cases this will set the correct image threshold for the cameras, though fine tuning may be necessary. Keyboard Shortcuts: A = Auto threshold selected image</p>
	<p>Clicking these buttons manually increases or decreases the selected camera's pupil threshold. Keyboard Shortcuts: ↑ and ↓ = increase and decrease threshold</p>
	<p>In Pupil-CR mode, these buttons manually increase or decrease the selected camera's corneal reflection threshold. Keyboard Shortcuts: + and - = increase and decrease corneal reflection threshold</p>
	<p>If available, use the arrow buttons to manually increase or decrease the head camera threshold. Keyboard Shortcuts: ↑ and ↓</p>

	<p>Select the tracking mode for recording. Here the Pupil-Corneal Reflection mode is selected.</p>
<p>Keyboard Shortcuts: P alternates Pupil only or Pupil-CR mode selection</p>	
	<p>Select the sampling rate for recording (250 Hz selected) Note: 500 Hz is not available in Pupil-CR mode.</p>
<p>Keyboard Shortcuts: F = alternates Sampling Rate selection</p>	
	<p>Toggle display of crosshairs in eye camera images. Keyboard Shortcuts: X = toggle crosshair display</p>
	<p>Toggle display of threshold coloring in eye camera images.</p>
<p>Keyboard Shortcuts: T = toggle threshold coloring display</p>	
	<p>Select to present the camera display image on the Display PC Monitor (where supported).</p>
	<p>Click on the desired image thumbnail to select the camera to display as a large image. Here the Right Eye camera is selected as indicated by the purple border. Image thresholds and status are indicated below each thumbnail.</p>
<p>Keyboard Shortcuts: ← and → to move left or right on image row</p>	
	<p>Select the eye(s) to track during recording. Here the Right eye is selected. The “Lock Tracked Eye”</p>
<p>button disables the ability to switch the eye being tracked from the Display PC. Keyboard Shortcuts: B=track both eyes; R = track Right eye; L = track Left eye</p>	
	<p>Click to go to the screen visited prior to the ‘Camera Setup’ screen. Keyboard Shortcuts: ESC = exit ‘Camera Setup’</p>
	<p>Click to go to the EyeLink II offline screen. Keyboard Shortcuts: ESC = go to ‘Offline’ screen</p>
	<p>Click to go to the ‘Output’ screen, from which a manual recording session can be conducted. This is most useful when operating in standalone mode.</p>
<p>Keyboard Shortcuts: O = go to ‘Output’ screen</p>	

Set Options	Click to go to the 'Set Options' screen, where a variety of system options and settings can be configured.
Keyboard Shortcuts: S = go to 'Set Options' screen	
Help (F1)	Click to access the on-line help page for 'Camera Setup'. All available key shortcuts are presented.
Keyboard Shortcuts: F1 = open Help screen	
Calibration	Click to go to the 'Calibrate' screen. After setting up the eye cameras and thresholding, calibrate the system.
Keyboard Shortcuts: C = go to 'Calibrate' screen	
Validation	Click to go to the 'Validate' screen. Validation allows you to get a sense of the gaze position accuracy of your
Calibration. Validation should always be run after Calibration.	
Keyboard Shortcuts: V = go to 'Validate' screen	
Drift Correction	Click to go to the 'Drift Correct' screen. Drift Correction can be performed before and during an experiment;
allowing gaze position to be realigned if headband slippage or significant pupil	
size change has increased gaze calculation error.	
Keyboard Shortcuts: D = go to 'Drift Correct' screen	

2.3.2.3 Camera Setup Screen Key Shortcuts

Key	Function
← and ⇒	Select camera to display and set up
R	Select Right eye for recording
L	Select Left eye for recording
B	Select Both eyes for recording
P	Toggle Pupil only or Pupil-CR mode selection
F	Toggle sampling frequency selection
A	Auto threshold selected image
X	Toggle crosshair display
T	Toggle threshold coloring display
↑ and ↓	Increase and decrease threshold
C	Go to the 'Calibrate' screen
V	Go to the 'Validate' screen
D	Go to the 'Drift Correct' screen
O	Go to the 'Output' screen
S	Go to 'Set Options' screen
F1	Open the Help dialog, in the help screen there is a brief overview of the role of this page and the key functions for it
ESC	Go to the 'Offline' screen or exit camera setup

2.3.3 Set Options Screen

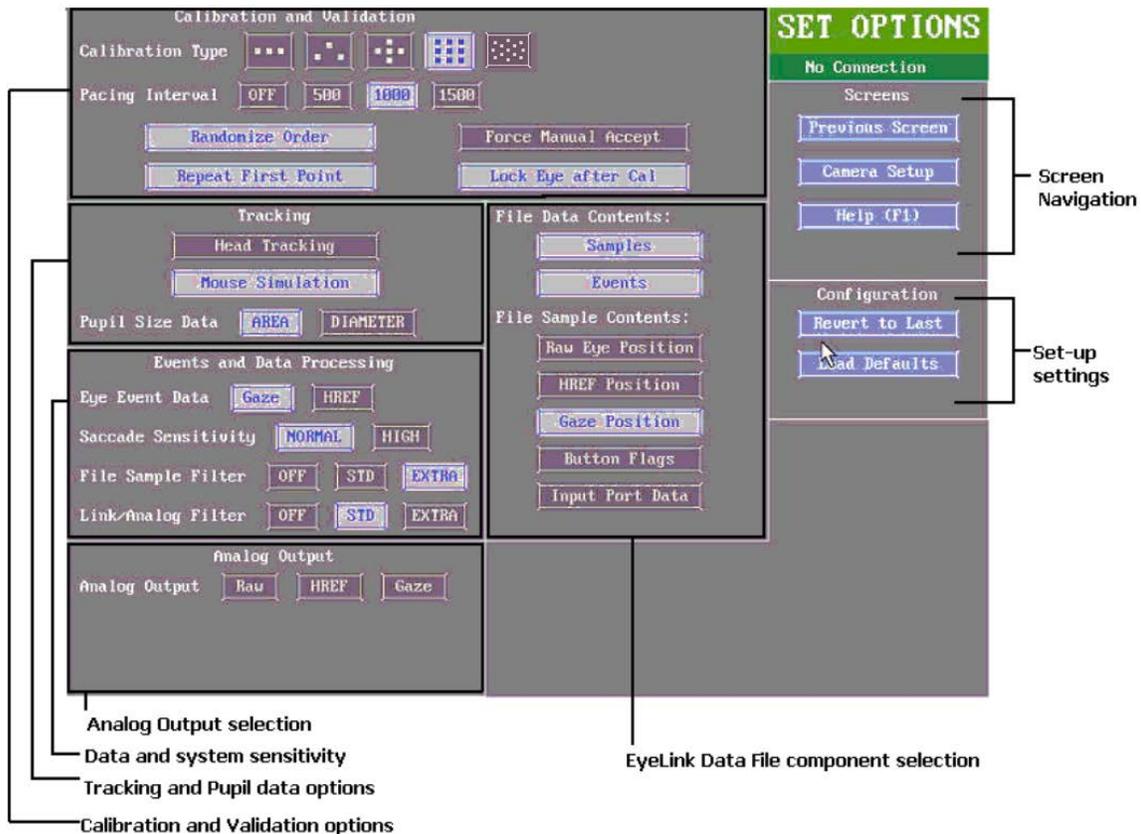


Figure 2-4 EyeLink II Set Options Screen

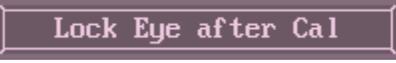
2.3.3.1 Set Options Screen Purpose

The 'Set Options' screen allows many tracker options to be configured manually. This is useful when doing manual recording sessions that are not driven by a Display PC using the EyeLink II API. When using the EyeLink II API to drive stimulus presentation, these settings are normally set by the Display application via a set of API calls.

Note that commands coming across the link from the Display PC can override selections made on this screen. All of the options can be configured at run time by a Display PC application for consistency across experimenters and data collection sessions.

The Default Settings (see Figure 2-4) should be sufficient for many tracking applications.

2.3.3.2 Set Options Screen Main Functions

<p>Calibration Type     </p>	<p>Select the Calibration Type for recording. The more points sampled, the greater the accuracy that can be expected. A 13-point calibration is ideal for displays with large angular extent. Keyboard Shortcuts: C=alternates between the Calibration Type selected</p>
<p>Pacing Interval    </p>	<p>Select the delay in milliseconds between calibration or validation targets if automatic target detection is active (Force Manual Accept is disabled). Keyboard Shortcuts: P = alternates between Pacing options</p>
<p></p>	<p>Randomize the target presentation order during calibration and validation. Keyboard Shortcuts: R = toggles Randomize Order on / off</p>
<p></p>	<p>Redisplay the first calibration or validation target at the end of the sequence. Keyboard Shortcuts: I = Repeat First Point</p>
<p></p>	<p>If enabled, requires manual pressing of the spacebar or ENTER key on Host or Display PC in order to gather the sample when the subject is looking at each calibration or validation target. If disabled, the calibration and validation procedure automatically samples once the eye settles. Keyboard Shortcuts: Y = toggle Force Manual Accept on/off.</p>
<p></p>	<p>Lock the Display PC keyboard out from changing the eye to record after calibration is performed.</p>
<p>Tracking</p> <p></p> <p></p>	<p>Head Tracking mode performs compensation for head movement to gaze position. In Mouse Simulation mode the Host PC mouse simulates eye movements and can be used for experiment debugging purposes. Keyboard Shortcuts: H = toggles Headtracking and Mouse Simulation modes</p>
<p>Pupil Size Data  </p>	<p>Report the pupil size as a function of pupil Area or Diameter in raw camera image units. Keyboard Shortcuts: S = alternates pupil size Area or Diameter</p>
<p>Eye Event Data  </p>	<p>Select whether to record eye events (fixations and saccades) in Gaze or HREF coordinates. Gaze is screen gaze x, y; HREF is head referenced-calibrated x, y Keyboard Shortcuts: E = alternates Gaze and HREF settings</p>
<p>Saccade Sensitivity  </p>	<p>Defines the sensitivity of the online parser for saccade event generation. Normal is intended for cognitive tasks like reading; while High is intended for psychophysical tasks where small saccades must be detected. Keyboard Shortcuts: X = alternates between Saccade Sensitivity levels</p>

File Sample Filter	OFF	STD	EXTRA	<p>Select the filter level of data recorded to the EDF file. Each increase in filter level reduces noise by a factor of 2 to 3.</p> <p>Keyboard Shortcuts: F2 = toggles File Sample Filter levels</p>
<p>Note: By changing the file sample filter from high to another value this will affect EyeLink Data Viewer and other analysis tool calculations. SR Research Ltd recommends leaving this value set to EXTRA.</p>				
Link/Analog Filter	OFF	STD	EXTRA	<p>Select the filter level for data available via the Ethernet link. Each increase in filter level reduces noise by a factor of 2 to 3 but introduces a 1-sample delay to the link sample feed.</p> <p>Keyboard Shortcuts: A= toggles Filter</p>
File Data Contents:	<p>Selecting 'Samples' will record data samples to the EDF file, and selecting 'Events' will record on-line parsed events.</p> <p>Keyboard Shortcuts: F = toggles File Data Contents</p>			
Samples				
Events				
Raw Eye Position	<p>Save the raw (x, y) coordinate pairs from the camera to the EDF file.</p> <p>Keyboard Shortcuts: 3 = toggle record Raw Eye Position on/off</p>			
HREF Position	<p>Record head-referenced eye-rotation angle (HREF) data in the EDF file.</p> <p>Keyboard Shortcuts: 4 = toggle record HREF Position on/off</p>			
Gaze Position	<p>Record gaze position data in the EDF file.</p> <p>Keyboard Shortcuts: G = toggle Gaze Position recording</p>			
Button Flags	<p>Record status of button box buttons in the EDF file.</p> <p>Keyboard Shortcuts: B = toggle Button Flag recording</p>			
Input Port Data	<p>Record external device data (from the parallel port or EyeLink Analog Card) in the EDF file.</p> <p>Keyboard Shortcuts: I =toggle Input Port Data recording</p>			
Previous Screen	<p>Click to view previous screen.</p> <p>Keyboard Shortcuts: ESC= Previous Screen</p>			
Camera Setup	<p>Click to view 'Camera Setup' screen.</p> <p>Keyboard Shortcuts: ENTER = Camera Setup</p>			
Help (F1)	<p>Click to access the on-line help page for the 'Set Options' screen. Keyboard shortcuts are listed on the Help screen.</p> <p>Keyboard Shortcuts: F1 = open Help screen</p>			
Configuration	<p>Clicking 'Revert to Last' restores settings to those active at the beginning of the current session, which were also the settings active at the end of the last session.</p> <p>Clicking 'Load Defaults' reverts to settings specified in the DEFAULTS.INI file.</p> <p>Keyboard Shortcuts: L= Revert to last configuration from last session; D= Loads default configuration.</p>			
Revert to Last				
Load Defaults				

2.3.3.3 Set Options Screen Key Shortcuts

Key	Function
C	Calibration Type
P	Pacing Delay (For auto-sequence)
R	Randomize calibration order
1	Repeat first point of calibration
H	Head tracking on/off
M	Mouse simulation of eye
S	Pupil size type
E	Eye event data (to saccade detector)
X	Saccade detector sensitivity
F2	File sample data filter level
F3	Link/Analog data filter level
F	File data contents selection
3	Raw eye position in samples
4	HREF eye position in samples
G	Gaze position and resolution in samples
B	Button flags in samples
I	Input Port data in samples
A	Analog output data selection
ENTER	Camera Setup screen
ESC	Return to previous screen
F1	HELP screen
L	Revert to configuration from last session. This is still saved even when the PC is turned off.
D	Load default configuration (Default.ini)

2.3.4 Calibrate Screen

2.3.4.1 Calibrate Screen Purpose

Calibration is used to collect fixations on target points, in order to map raw eye data to either gaze position or HREF data. Targets are presented for the participant to fixate on the Display PC while feedback graphics are presented to the experimenter on this display. The calibration is automatically checked when finished, and diagnostics given.

Calibration should be performed after camera setup and before Validation.

The three camera images, along with three threshold values, are at the bottom left of the screen. The eyes to be calibrated as well as the calibration type (as defined in the Set Options screen or via the EyeLink API) are indicated beside the three camera images at the bottom of the screen. The calibration status and current calibration point being presented are indicated on the bottom right of the screen.

To perform a calibration, have the participant look at the first fixation point and press the “Accept Fixation” button, or the ENTER or the Spacebar, to start the validation. If auto trigger is not enabled, repeat this action after each target fixation.



Figure 2-5 EyeLink II Calibrate Screen

2.3.4.2 Calibrate Screen Main Functions

Camera Setup	Click to go to the ‘Camera Setup’ screen. Keyboard Shortcuts: ENTER = ‘Camera Setup’ screen
Help (F1)	Click to access the on-line help page for the ‘Calibrate’ screen. all keyboard shortcuts are presented. Keyboard Shortcuts: F1 = Help screen
Abort	Terminate Calibration sequence. Keyboard Shortcuts: ESC = Abort
Restart	Click to restart the Calibration process.
Auto Trigger	Click for automated calibration sequence. Sequence pacing is selected in the ‘Set Options’ screen. Keyboard Shortcuts: A = Auto Trigger
Accept Fixation	Click to accept fixation value, after the participant’s gaze is stable on the target. Keyboard Shortcuts: ENTER = Accept Fixation

2.3.4.3 Calibrate Screen Key Shortcuts

Key	Function
F1	Help screen
ESC	Camera setup
A	Auto calibration set to the pacing selected in Set Options menu. (Auto trigger ON). EyeLink accepts current fixation if it is stable.
<u>During Calibration</u>	
ENTER	Begins calibration sequence or accepts calibration value given.
ESC	Terminates calibration sequence.
M	Manual calibration (Auto trigger turned off.)
A	Auto calibration set to the pacing selected in Set Options menu. (Auto trigger ON). EyeLink accepts current fixation if it is stable.
<u>After Calibration</u>	
F1	Help screen
ENTER	Accept calibration values
V	Validate calibration values
ESC	Discard calibration values

2.3.5 Validate Screen

2.3.5.1 Validate Screen Purpose

The Validate screen displays target positions to the participant and measures the difference between the computed fixation position and the fixation position for the target obtained during calibration. This error reflects the gaze accuracy of the calibration. In addition, the average offset is used to perform an immediate drift correction. The functionality available in the Validate screen is very similar to that of the Calibrate screen.

Validation should only be performed after Calibration.

To perform a validation, have the subject look at the first fixation point and press the “Accept Fixation” button, or the ENTER or Spacebar key, to start the validation. If auto trigger is not enabled, repeat this action after each target fixation.



Figure 2-6 EyeLink II Validate Screen

2.3.5.2 Validate Screen Main Functions

Camera Setup	Press to go to the Camera Setup screen. Keyboard Shortcuts: = ESC
Help (F1)	Click to view the help menu for the Validate screen Keyboard Shortcuts: = F1
Abort	Click to reject the Validation value given and revert to the 'Calibrate' screen Keyboard Shortcuts: = ESC
Restart	Click to restart the Validation process
Accept Fixation	Click to accept fixation value, after the participant's gaze is stable on the target. Keyboard Shortcuts: ENTER = Accept Fixation

2.3.5.3 Validate Screen Key Shortcuts

Key	Function
F1	Help screen
ESC	Camera setup
A	Auto calibration set to the pacing selected in Set Options menu. (Auto trigger ON). EyeLink accepts current fixation if it is stable.

During Validation	
ESC	Exit to Camera Setup
F1	Help screen
M	Manual validation (Auto trigger turned off.)
A	Auto validation set to the pacing selected in Set Options menu. (Auto trigger ON). EyeLink accepts current fixation if it is stable.
After Validation	
F1	Help screen
ENTER	Accept validation values
V	Validate validation values
ESC	Discard validation values

2.3.6 Drift Correct Screen



Figure 2-7 EyeLink II Drift Correct Screen

2.3.6.1 Drift Correct Screen Purpose

The drift correct screen displays a single target to the participant and then measures the difference between the computed fixation position during calibration / validation and the target. This error reflects headband slippage or other factors, which are then corrected for by the measured error.

To perform a drift correction, have the subject look at the first fixation point and press the “Accept Fixation” button, or the ENTER or Spacebar key to sample the eye position.

If the drift correction error is too large, the drift correction will be performed again. If the total drift since the last calibration is too large, the drift correct will fail and you will be prompted to perform another calibration.

2.3.6.2 Drift Correct Screen Main Functions

Camera Setup	Click to go to the ‘Camera Setup’ screen. Keyboard Shortcuts: = ESC
Help (F1)	Click to view the help menu for the ‘Validate’ screen Keyboard Shortcuts: = F1
Abort	Stop the drift correction.
Restart	Restart the drift correction process
Auto Trigger	Not Used
Accept Fixation	Click to accept fixation value, after the participant’s gaze is stable on the target. Keyboard Shortcuts: ENTER = Accept Fixation

2.3.6.3 Drift Correct Screen Key Shortcuts

Key	Function
ENTER	Begins or accepts
ESC	Rejects drift correction value if one has been created or exits drift sequence.
F1	Help screen

2.3.7 Output Screen

2.3.7.1 Output Screen Purpose

The Output screen is used to observe and initiate the recording of eye movement data. Data files (EDF files) may be opened and messages added, or data may be output via the optional Analog output card. Data file contents are controlled from the ‘Set Options’ screen.

Recording may be manually started from the Output screen, or by an application via the Ethernet link. Manual recording may be terminated by switching back to the to the OUTPUT screen. If the recording was initiated, and a menu of options will appear allowing faster drawing and file transfer.



Figure 2-8 EyeLink II Output Screen

2.3.7.2 Output Screen Main Functions

Previous	Press to go to the Previous screen. Keyboard Shortcuts: ESC = Previous Screen
Camera Setup	Press to go to the Camera Setup screen. Keyboard Shortcuts: ESC = Camera Setup
Output	Click to go to the 'Output' screen, from which you can start a manual recording session. Keyboard Shortcuts: O = go to 'Output' screen
Help (F1)	Click to access the on-line help page for the current screen. All available key shortcuts are listed on the Help screen. Keyboard Shortcuts: F1 = open Help screen
RECORD	Click to begin recording data. Keyboard Shortcuts: Enter or O
Open File	Click to open EDF file Keyboard Shortcuts: F = Open File

2.3.7.3 Output Screen Key Shortcuts

ESC	Camera Setup Screen
ENTER or O	Start recording
S	Set options screen
F1	Help screen
F	Opens EDF File

2.3.8 Record Screen



Figure 2-9 EyeLink II Record Screen

2.3.8.1 Record Screen Purpose

A menu of options allows opening and closing (EDF) files, setting data to be recorded, analog output type, and other output-related options. This mode always precedes manual entry into Output mode, to allow parameter preview.

This is the only mode in which analog data is produced, and is usually the source mode for link and file data. Any graphics drawn on the idle-mode screen are re-displayed on the screen, to be used as a reference for the real-time gaze-position cursor.

2.3.8.2 Record Screen Main Functions

	Stops the recording of data to the EDF file. Keyboard Shortcuts: ESC = 'Stop Recording'
---	--

2.3.8.3 Record Screen Key Shortcuts

ESC	Exit to output screen
CTRL + ALT + A	Abort trial menu
After Trial Aborted	
S	Setup (Calibrate, camera setup)
R	Repeat Trial
N	Next Trial
CTRL + ALT + T	Terminate Experiment
CTRL + ALT + Q	Terminate program

2.4 Status Panel

The Status Panel allows users to monitor the status of the camera images throughout the setup, calibration, validation and recording phases of every experiment. A visual indicator, illustrated in Figure 2-10 is present on the right hand side of the Calibrate, Validate, Drift Correct, Output and Record screens and gives the operator a complete and continuous status report of the camera images.



Figure 2-10 EyeLink II Status Panel

For the Pupil and Corneal sections of the Status Panel, the left column corresponds to the left eye and the right column corresponds to the right eye. If using a monocular recording set-up, the status column representing the eye not being used is disabled. The Status Panel indicators are summarized as follows:

Pupil

OK (green) Pupil present and can be tracked at selected sample rate
SIZE (yellow) Occurs in pupil only 500 Hz and pupil – CR tracking modes when the pupil size is larger than the maximum allowed pupil size.
MISSING (red) Pupil not present

Corneal (only operational in Pupil-CR mode)

OK (green) Corneal reflection is present and can be tracked
MISSING (red) Corneal reflection is not present

Markers (only operational when head tracking is enabled)

OK (green) All IR-Markers are being tracked by the head camera
MISSING (red) At least one IR-Marker is missing from the head camera
CONFIG (red) The head camera is seeing more than 4 IR sources

When working in the Output and Record screens, if the Pupil Size warning is on, at least one sample was interpolated by the system and is indicated by **(Int)** appearing beside the 'Pupil' label in the Status Panel. All status flags remain on for a minimum of 200 msec, even if the condition that caused the warning or error to be raised lasted for less than 200 msec.

2.5 Mouse Simulation Mode

You can use a mouse on the EyeLink II Host PC to simulate an eye to practice calibration and tracking alone or to test experiments during development if a test subject is not available. Select 'Mouse Simulation' in the 'Set Options' screen or use the '-m' command line option to enable mouse simulation.

2.6 Configuration Files and Experiment Directories

Most EyeLink II options can be configured through the Host application's graphical user interface, however there are some lower level options that are specified by editing the configuration files (*.INI) or by sending commands from the Display PC via the Ethernet link. The configuration files are loaded by EyeLink II from the current directory (where 'EYELINK2' was typed from) and if not found there, from the directory containing the host application (C:\EYELINK2\EXE).

This makes it possible to create custom configurations for experiments without editing the files in the C:\EYELINK2\EXE directory, by placing the modified versions of the *.INI files in the directory where the EyeLink tracker is invoked from. If your experiment will be using option settings that are non-standard for your lab, it makes sense to create a directory on the EyeLink Host PC for the experiment, copy any configuration files into this directory that need to be modified for this experiment, and to invoke the tracker from this directory.

The EDF files for an experiment are written to a disk partition and directory based on the parameters set in the DATA.INI file. The default parameters specify that data is written to a disk partition called "DATA" and to a root directory called "EDF". If this partition / directory is not found, the data is written to the directory that the EYELINK2.EXE was started from. As mentioned above, you can specify an experiment specific data directory by copying the DATA.INI file to your experiments launch directory and modifying the "data_drive_name" and "data_drive_directory" parameters.

In addition, other optional .INI configuration files are required if scene camera, and video overlay options are installed in your system. If you plan to change the default settings in the .INI files, please cut and paste the target commands to the final.ini and make the modification in that file for the ease of future maintenance.

This is a list of all EyeLink configuration files, and what they control:

EYELINK2.INI	The main configuration file, includes in other INI files.
LASTRUN.INI	The thresholds, menu choices etc. from the last session.
DEFAULTS.INI	Default settings for all items in LASTRUN.INI: can be loaded from Setup menu.
EYENET.INI	Setup for Ethernet link: driver data, TCP/IP address.
PHYSICAL.INI	Monitor, head-camera and display pixels resolution settings. All physical setup and simulation settings.
DATA.INI	Specifies where EDF files should be written to on the Host PC. Controls data written to EDF files, link.
PARSER.INI	On-line parser data types, configuration, saccadic detection thresholds. SR RESEARCH DOES NOT SUGGEST MODIFYING THIS FILE.
KEYS.INI	Special key function definitions, default user menus.
BUTTONS.INI	Hardware definition of buttons, special button functions. Preconfigured for Microsoft SIDEWINDER PLUG&PLAY.
ANALOG.INI	Optional analog output hardware interface configure, clock/strobe control.
COMMANDS.INI	Lists some useful EyeLink commands for controlling the host application via your own program.

Table 1: EyeLink II Configuration Files

2.7 Analog Data Types

Position data and pupil size data are available in several types, which are selectable through the 'Set Options' screen. For pupil size, either pupil area or pupil diameter may be monitored. These are very high-resolution measurements in camera units, with a typical per-unit resolution of 5 μm (0.005 mm). Pupil size measurements are affected by eye position, due to the optics of the eye and cameras.

Position data output can be selected from one of three types of measurement:

- Raw:** This measurement is the raw pupil-center position (or pupil minus corneal if running in pupil-CR mode) as measured by the image-processing system. This measurement is available without performing an eye-tracking calibration, but cannot use the EyeLink II head-position compensation system.
- Href:** This measurement is related to the tangent of the rotation angle of the eye relative to the head. In the default EyeLink II setup, and for the -5V to +5V output range, it is $5V \cdot \tan(\text{angle})$, measured separately for vertical and horizontal rotations. A calibration must be performed to properly obtain this measure.
- Gaze:** This is actual gaze position on the display screen, fully compensated for head position. A calibration must be performed to obtain this measure.

The EyeLink II system offers integrated data recording and digital data transfer methods, which do not suffer from the timebase, resolution, and noise degradation inherent in analog systems.

3. An EyeLink II Tutorial: Running an Experiment

The following session will demonstrate and test the EyeLink II system. A summary of the setup procedure can be found at the end of the discussion. This section leads you through a straightforward subject setup and Pupil-CR (pupil – corneal reflection) monocular eye-tracking demonstration. For the easiest setup, you should select a subject for the test that can sit still when required, and does not have eyeglasses. Once comfortable setting up these subjects, you can tackle more difficult setup problems.

During the session description we take the opportunity to discuss many important aspects of system use. These may make the setup appear long, but a practiced experimenter can set up a subject in less than three minutes, including fitting, calibration, and validation.

If the EyeLink II Host application software is not yet running on the Host PC, start it by typing

```
CD C:\EYELINK2\EXE ↵  
EYELINK2 ↵
```

IMPORTANT: Remember to exit the EyeLink software by pressing the key combination CTRL+ALT+Q. Do not switch off the computer while running the EyeLink II software, as data may be lost.

Now start a simple sample example application on the Display PC. TRACK.EXE is available on most Windows installations that have the Windows Display Software installed, though the path and menu location may vary depending on the Windows installation. Look for TRACK under the Start Menu in:

Start->Programs -> SR Research -> EyeLink -> TRACK.EXE

When TRACK starts, a copyright message will appear on the Display PC, and the status message (at the top right) should read “TCP/IP Link Open” on the Host PC.

A dialog will appear on the Display PC asking you to enter a Track EDF file name. Enter “TEST”, without the “ ” or leave the default entry.

Once TRACK is running, control is either from the Host PC or Display PC keyboard, and the application will respond the state of the EyeLink II software by drawing appropriate graphics on the Display PC. The advantage of the Display PC based control is that it allows the operator to work near the subject, or for self-setup. We will perform most of the EyeLink II setup by using the Host PC keyboard.

3.1 The Camera Setup Screen

The first step in an eye-tracking session is to set up the participant and eye tracker. Begin by pressing ↵ (ENTER) on the Host PC's keyboard to display the Camera Setup screen. You will see three camera-image windows near the bottom of the display, and a large image of the selected camera in the middle of the display. Navigation buttons to access other Host PC screens are on the right, while selection buttons for tracking mode and other functions are on the left of the screen.

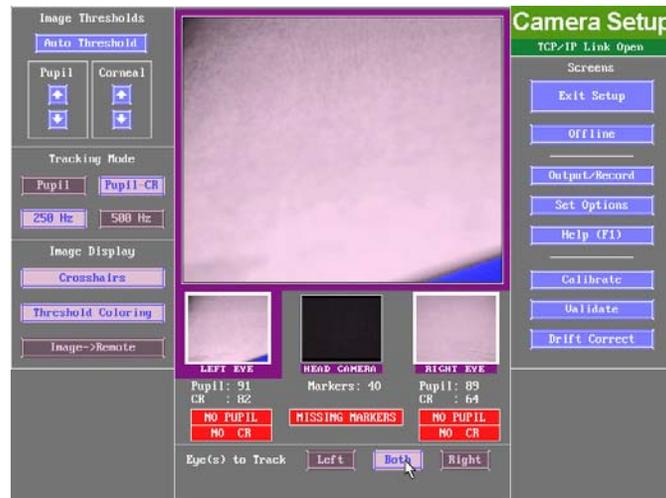


Figure 3-1: Example Camera Setup Screen without subject.

Throughout the EyeLink II software, you can use the Host PC mouse to select options and navigate throughout the Host Application. Almost every button has an equivalent key shortcut. The key shortcut mappings are always available for the currently displayed screen can be accessed via the Help button, or by pressing F1.

In the Camera Setup screen, you can select one of the three camera views by selecting the small camera image you are interested in with the mouse or by pressing the ← and ⇒ keys. If an experiment using the EyeLink API is open on the Display PC (like TRACK.EXE) then pressing the “Image → Remote” button from the Camera Setup screen will start the display of an image of the selected camera on the Display PC's monitor. The ← and ⇒ keys from the Display PC can be used to change cameras from this display.

HINT: If the Display PC application was programmed using the Display API then all keystrokes on the Display PC keyboard control the Host PC application as though they were typed on the Host PC keyboard.

3.2 Fitting the Headband

To practice setting up the eye cameras, you will need a subject to wear the headband. If none is available, you can practice this part of the procedure on yourself. It is actually easier to practice on yourself first, but be sure to repeat with several subjects later. Because all keys on the subject keyboard are sent to the EyeLink software by TRACK, you can practice calibration and observe your tracked eye-position too. Since no menus appear on the Display PC, you will have to be able to see the Host PC display as well.

NOTE: The EyeLink system should run for 5 minutes after switching on power to the Host PC, to prevent small drifts in thresholds. It is normal for the eye cameras and the electronics box to run slightly warm to the touch.

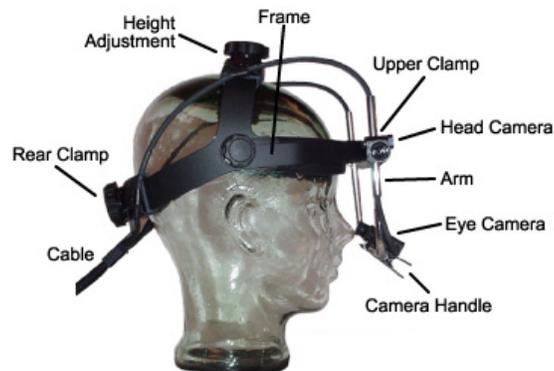


Figure 3-2: Parts of the EyeLink Headband

Some care should be used in applying and removing the headband from the subject to prevent the eye cameras from coming into contact with the subject's eyes, nose, or eyeglasses. Figure 3-3 shows a simple yet safe sequence. Begin by opening the headband as wide as possible using the clamp knob at the back. Hold the headband with the front high, and place the back of the headband in contact with the head, just above the base of the subject's skull. With the headband in contact with the back of the head, lower the front of the headband. Watch the eye cameras carefully to prevent contact with the face or glasses! Also, check that no hair is between the front pad of the headband and the forehead, as this will cause the headband to slip.

To remove the headband, do the reverse procedure: open the headband to its maximum size, carefully raise the front of the headband above the head while keeping the back of the headband in contact with the skull, then lift the headband up. Use a dummy head (glass or foam, available from wig shops or novelty shops) to store the headband. This will prevent disturbance or damage

of the eye cameras, and because the eye camera position is preserved, setup of the next subject will be faster.

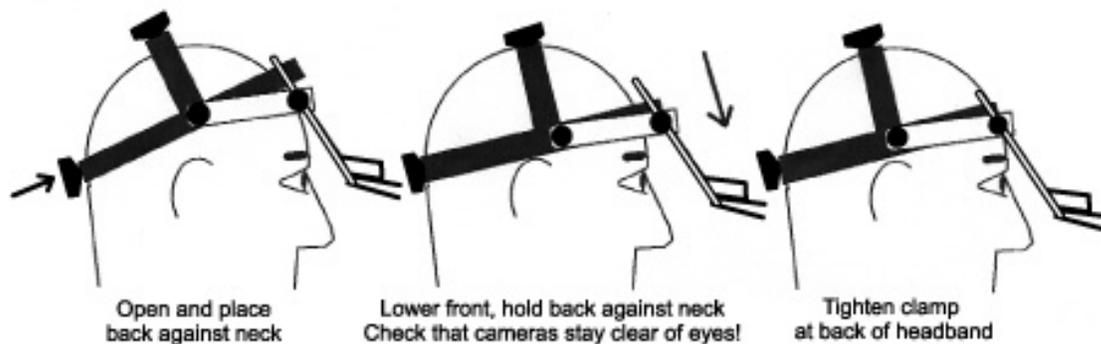


Figure 3-3: Applying and removing headband

Fit the headband so the front pad is in the centre of the forehead, and adjust the height of the headband (with the top knob) so the sides are just above the subject's ears. Check that the head camera is centred above the subject's nose (Figure 3-4). There is a notch centred on the bottom of the head camera bar to help in centring the headband; this is particularly useful when setting up the headband on yourself. Tighten the headband with the rear clamp knob, turning the knob until some resistance is felt then backing off by one notch. The headband should be secure enough to prevent slipping, but not over tight.

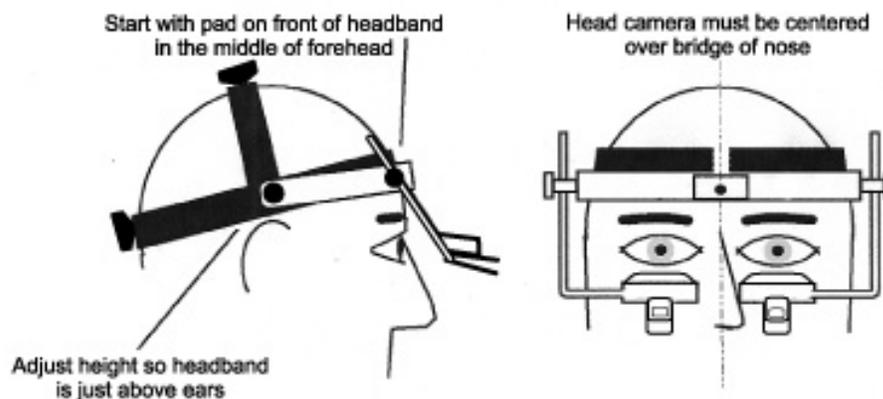


Figure 3-4: Initial Positioning of the Headband

The headband cable should not hang down from the back of the headband to the floor: this will unbalance the headband and exposes the cable to damage from shoes and chair casters. One treatment for the cable is to suspend it from above the subject, with a loop of slack descending about 30 cm below the back

of the headband. Alternatively, a butterfly clamp can be positioned 40 cm down the cable from the headband, and clipped to the back of the subject's collar.

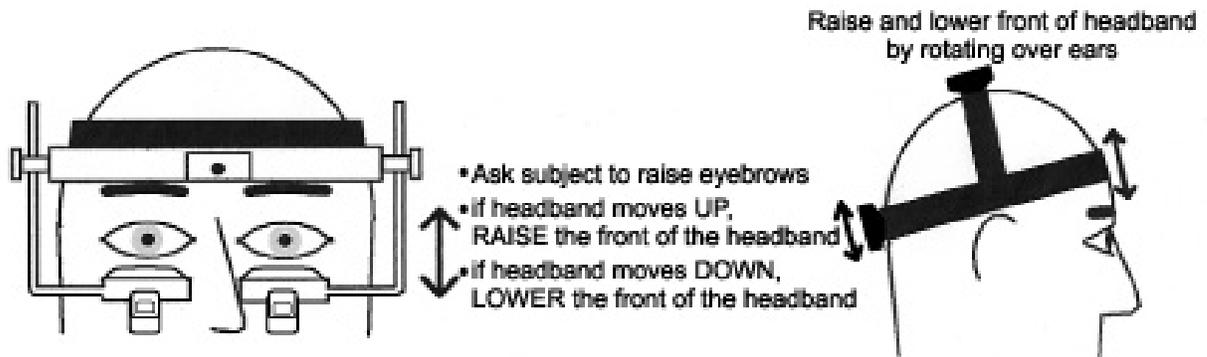


Figure 3-5: Adjusting point of contact with forehead.

The stability of the headband depends on proper placement on the subject's head. Especially important is the position of contact between the forehead and the headband. Because of the anatomy of the scalp muscles, the best position may vary for each subject. Begin by placing the headband loosely on the head, about halfway between the hairline and eyebrows. Now ask the subject to raise and lower their eyebrows (Figure 3-5). If the headband can be seen to shift in the direction of eyebrow motion, the headband should be refitted higher on the forehead. If the headband moves opposite to the eyebrow movement, fit it lower.

3.3 Adjusting the Head Camera Position and Corneal Illuminators

Before beginning the process of eye camera setup, you need to ensure that the head camera bar, which also houses the corneal illuminators providing the source for the corneal reflection, is properly positioned so that the illuminators are directly above eyes.

From the Camera Setup screen, select the head camera image (the centre image). When the subject is looking at the Display PC monitor, the head camera image should show four large spots from the IR markers. The horizontal bar on the front of the headband should be pivoted downwards until the bar is over subject's eyebrows, or as low as is possible without occluding the subjects field of view (Figure 3-6). If this is not done, head-motion compensation and the corneal reflection will be degraded.

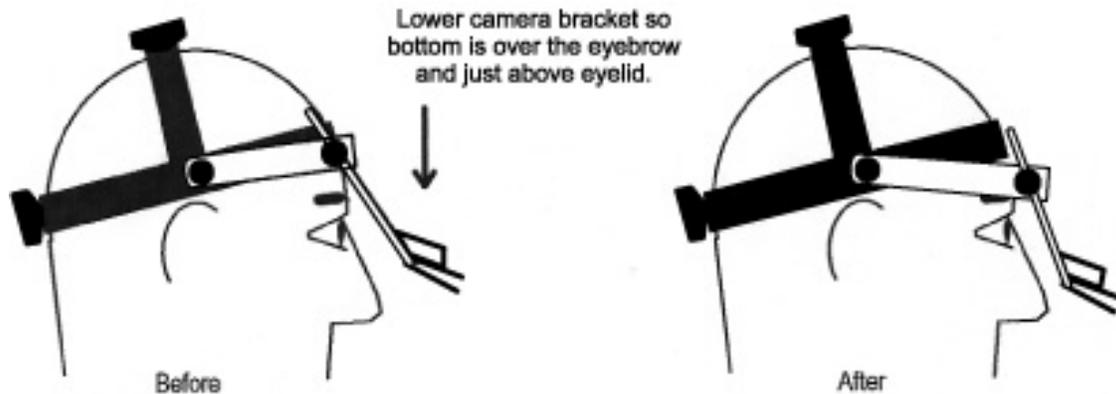
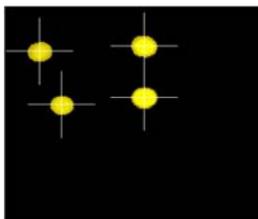


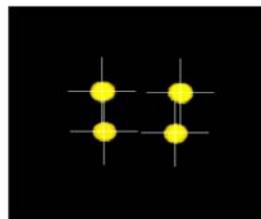
Figure 3-6: Positioning the camera bracket bar

IMPORTANT: If you are recording in Pupil-CR mode, it is extremely important to position the head camera bar as low as possible. This will maximize the ability of the corneal illuminators (the two white ellipses on the bottom of the head camera bar) to create a corneal reflection. You will know if the illuminators are not properly positioned if you get a poor corneal reflection after eye camera setup.

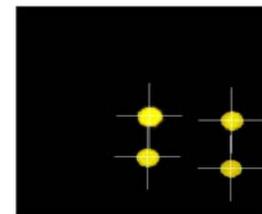
The image of the four IR markers should be positioned roughly centred in the image window (Figure 3-7). If any of these markers is near the top or bottom of the image, either the height of the subject's chair or the Display PC monitor will have to be adjusted. Usually this will not be required, unless the IR markers are positioned far above or below the height of the subject's gaze. If the IR markers are close to the left or right side of the image, ensure the headband is properly centred on the subject's head and that they are sitting centred in front of the Display PC monitor.



Move participants head position to the left and up



Good



Move participants head position to the right and down

Figure 3-7. Head camera position adjustment

If the images of any of the four markers is missing or noisy, ensure the head camera is selected in the Camera Setup screen and press the Auto Threshold

button (or A on the keyboard). The head camera auto threshold is automatically set when any of the eye camera images is viewed. This thresholding almost always is correct, however, if one or more markers is not shown in yellow, use the ↓ key to adjust the threshold. If extra blobs are seen in the image, there may be a source of bright infrared light such as a lamp or window in the head camera's field of view.

3.4 Adjusting Eye Camera Position

From the Camera Setup screen, select one of the eye cameras. Until the cameras have been properly aimed, you will probably not see the eye initially. Start by rotating the selected camera up and down until part of the eye comes into view. This is adjusted by lowering and raising the eye camera handle, as in the bottom row of Figure 3-8.

If the image becomes too dark or too light, wait one second while the auto-contrast adjusts itself. If the blue thresholded area in the display is interfering with setup, press the “Threshold Coloring” button (or ‘T’ on the keyboard) to remove the threshold color overlay. In TRACK, you can use keys on either the Display or Host PCs to perform all keyboard shortcut operations while the eye image is displayed.

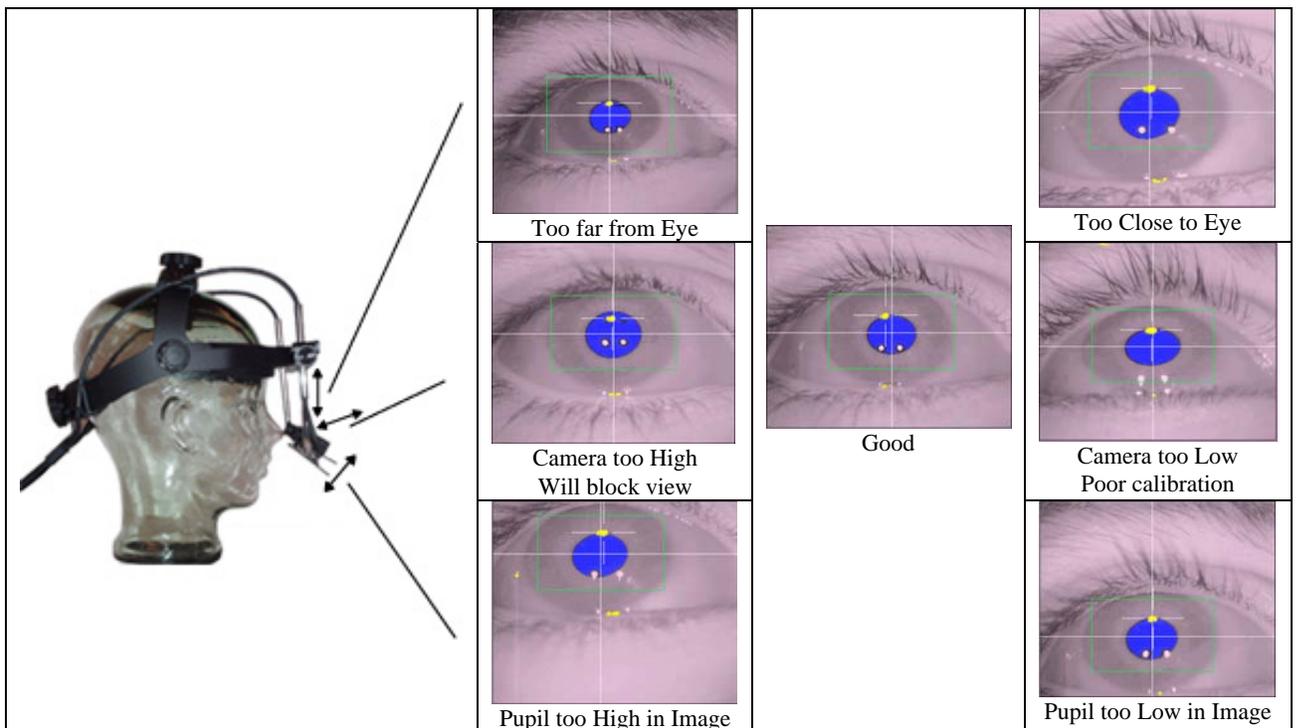


Figure 3-8: Size and Vertical Eye Camera Adjustments

The camera may be moved toward and away from the eye until the corners of the eye are just outside the image, as in the top row of Figure 3-9. If the eye image is too small, the eye tracking resolution will be poor; if too large, the pupil will leave the image at large eye rotations and be lost. Hold the eye camera with one hand, and loosen the rod clamp for that camera with the other hand by 1/2 turn. Slide the camera up or down through the rod clamp gently, adjusting the vertical position of the image to keep the eye in view. Remember to re-tighten the rod clamp after the adjustment.

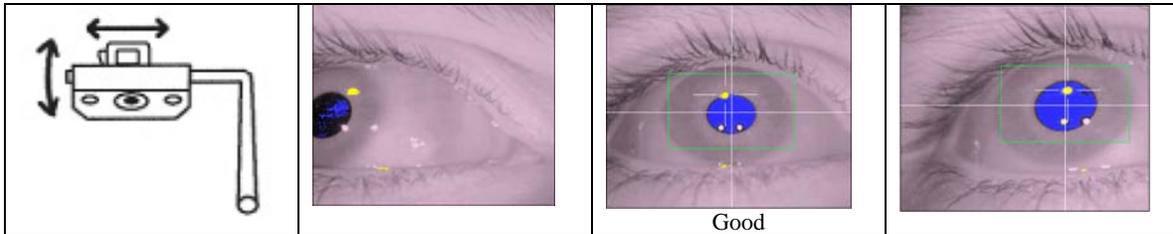


Figure 3-9: Horizontal Adjustments of Eye Camera

Finally, the height of the eye camera below the eye may need to be adjusted, as in the middle row of Figure 3-8. If the camera is too high, the subject's view of the bottom of the display may be blocked. If the camera is too low, the pupil may be hidden if the subject smiles or squints, and the calibration will be poor. The camera height is set by swinging the camera rod in and out.

The proper height may be set by the curvature of the lower eyelid in the image, or by observing the position of the corneal reflections in the camera image. If the lower eyelid curves up at the edges (smile shape) the camera should be lowered. If the lower eyelid curves up in the middle (frown shape) the camera should be raised. The position of the two eye illuminator corneal reflections (the two white circles) should be at the bottom of the pupil: lower the camera if they are too high.

Note: The corneal reflections mentioned here are not the corneal reflections used by the system for headband movement compensation and are white with a position that should be at the bottom of the pupil. The corneal reflection used in the Pupil-CR mode is a single circle and is yellow in colour, located near the top of the pupil.

The pupil of the eye must now be centred in the camera image. Two methods can be used, depending on the operator's preference and camera clamp mechanics. The camera may be loosened and slid left or right to centre the pupil. Squeeze the spring clamp handle to loosen and move the camera.

The second method is to move the nose end of the camera rod towards and away from the face, twisting the rod through the rod clamp. This may cause the

eye image to tilt as well, which is not a problem. This may require some practice: try setting up the headband on yourself, while watching the display on the operator monitor.

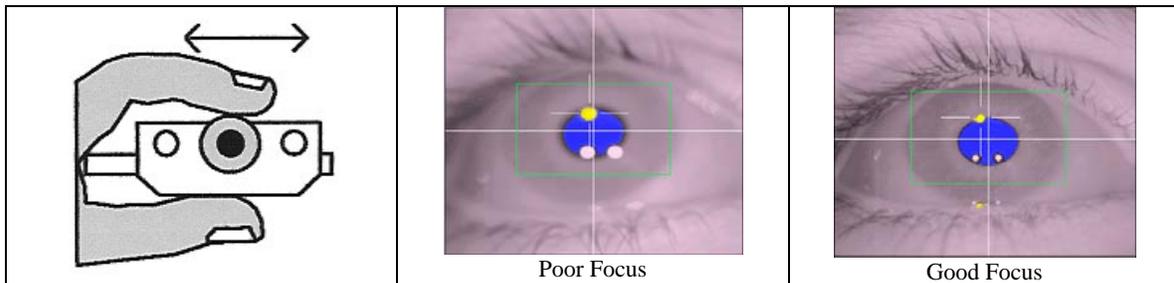


Figure 3-10: Focusing the Eye Camera

The eye camera should be focused by rotating the lens holder (Figure 3-10). The best focus will minimize the size of the two eye illuminator corneal reflections, which can be seen below the pupil and to each side. Turn the lens by placing your thumb on the bottom of the camera and turning the lens holder by sliding your index finger along the top of the camera. This will keep your fingers away from the subject's eyes, and prevent the camera image from being blocked. The focus may also change the size of the eye image, which may require the eye-camera distance to be reset.

3.5 Setting Pupil Threshold

The camera image of the eye should now be clear, with the pupil centred when the subject looks at the eye image on the Display PC's monitor. The pupil threshold may now be automatically set by pressing the 'Auto Threshold' button or the 'A' key when the eye camera image is selected. The pupil of the eye should be solidly blue, with no other colour in the image, when the thresholding is properly set. If large areas are colored, the subject may have blinked: press Auto Threshold again.

If the subject wears eyeglasses, reflections may block the pupil in the image. Reflections from the eye-camera illuminators can be reduced by placing the eye camera near the bottom of the eyeglass lens and aiming it up at the eye. If the eyeglasses have an anti-reflective coating, image contrast may be poor and pupil tracking may be noisy. Eyeglasses also can show bright images of the IR markers mounted on the subject monitor. These reflections are automatically reduced as much as possible by the EyeLink II system; however not every subject with glasses will be usable. Position the camera as close to the subject's glasses as possible to reduce noise.

The pupil threshold should be checked by looking at the green areas in the image. Figure 3-11 shows the symptoms to look for. If the threshold is too low, the blue area will be smaller than the pupil, and the eye tracker data will be excessively noisy. If the threshold is too high, there will be shadows at the edges and corners of the eye, especially when the eye is rotated. Adjust the pupil threshold by using the pupil threshold adjustment buttons or with the \uparrow and \downarrow keys: a mnemonic is to think of the \uparrow key as increasing the blue area, and the \downarrow key as decreasing the blue area.

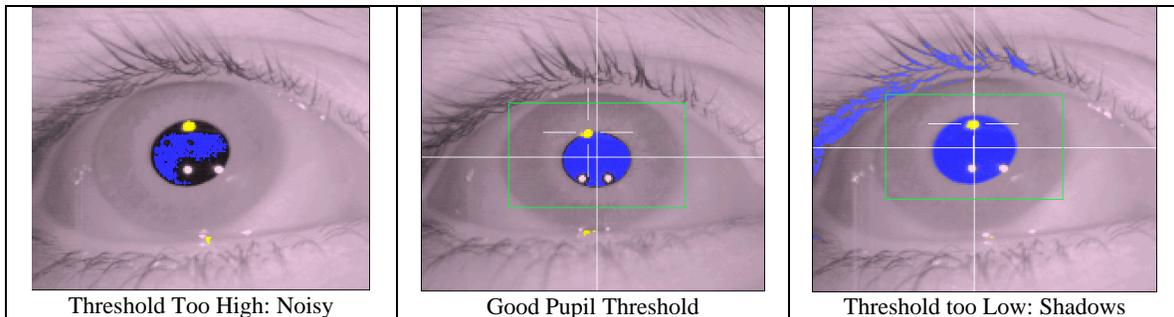


Figure 3-11: Symptoms of Poor Pupil Threshold

Have the subject turn their head slowly from side to side while they continue to look at the eye image on the subject monitor. Check for any or the conditions in Figure 3-12. One common problem is for shadows at the corners of the eye, which can capture the pupil. These may be eliminated by increasing the threshold with the \uparrow key. Be careful not to raise the threshold too much, as the pupil thresholding may be poor at other eye positions, as in the first image in Figure 3-12.

The pupil on the Host PC should have a box drawn around it, indicating that it has been detected. If a shadow captures the pupil, or it is clipped by the side of the camera window (as in Figure 3-12), the box will disappear and the pupil will be lost. On the Host PC, a red warning message will appear below the small camera image for the eye indicating “No Pupil”.

The threshold can also be checked and adjusted in the Camera Setup menu. The camera image display should now show a thresholded image of from all cameras, with the currently selected camera outlined in purple. You can use \uparrow and \downarrow to change the threshold on the selected camera, and \leftarrow or \rightarrow to change the selected image.

The Camera Setup display is updated very rapidly, so noise, shadows, etc. will be easily detected. You can have the subject look at the corners of the monitor, and watch the pupil image for problems. Pupil position can be seen by looking for the moving letter (‘L’ for left pupil, and ‘R’ for right pupil) in the data display

window at the bottom right. If the pupil is lost, its letter will disappear from the window.

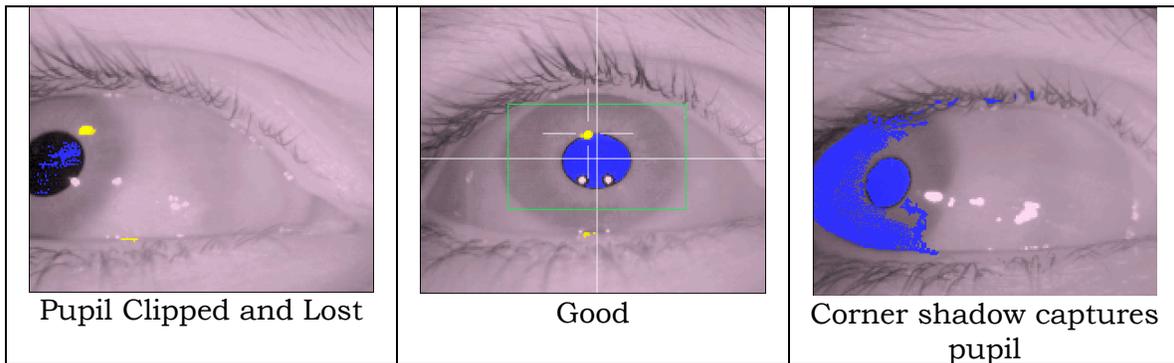


Figure 3-12: Corner Effects Seen with Head Rotation

Once you are satisfied with the eye-camera and pupil setup, you can select the other eye camera by pressing on the desired camera image or with the \leftarrow or \rightarrow keys.

NOTE: It is recommended that both eyes be setup for calibration, even if only one is to be monitored during the experiment. The EyeLink II system automatically selects the best eye for tracking after the validation stage of setup and uses that eye for recording during the experiment.

3.6 Setting Corneal Reflection (CR)

If recording will occur in Pupil-CR mode, first ensure that the correct tracking mode is selected in the Camera Setup screen. The corneal reflection, if present, is identified by a yellow circular shape surrounded by a crosshair.

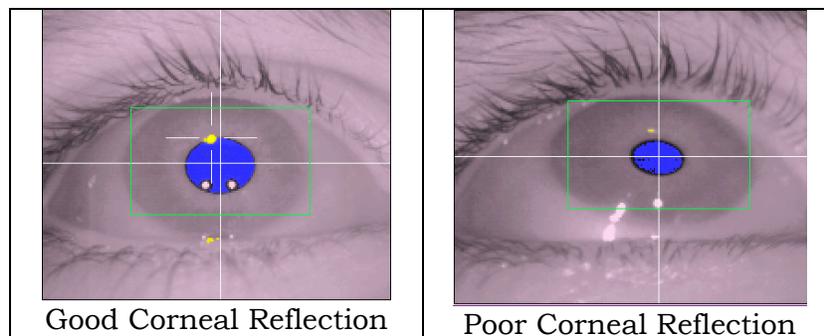


Figure 3-13: Corneal Reflection

Follow the following steps to acquire the best CR (Figure 3-13):

- a) Ensure the head camera bar is centered on the subject's face so the corneal illuminators are positioned over the center of each eye.
- b) Ensure the head camera bar is as low as possible (usually over the subject's eyebrows) so that the corneal illuminators are not occluded by the subject's eyelashes.
- c) Press the Auto Threshold button to set the CR threshold. You should see a yellow circle appear near the pupil on each eye. Auto Threshold should almost always set the correct CR threshold.
- d) If auto thresholding sets the threshold too low or high, use the CR threshold buttons, or the + and – keys, to manually adjust the CR threshold.
- e) Have the subject slowly look along the edges of the display surface and ensure that the corneal reflection does not get lost. If the CR does get lost, a red warning message will appear below the small camera image for the eye indicating “No CR” on the Host PC.

NOTE: Corneal reflection will not be stable with all subjects, particularly those wearing glasses with a heavy anti-reflection coating. If, after ensuring the corneal illuminators and cameras are positioned correctly and thresholding has been performed, you are unable to acquire a stable corneal reflection, it is suggested that you switch to pupil only mode for tracking of the subject.

3.7 Calibration

The preceding steps set up the EyeLink II camera system to track the positions of the pupils and CR of both eyes and of the four IR markers. Much lab-based eye-movement research requires information on the subject's point of gaze on a display of visual information, such as a screen of text. To compute this, we need to determine the correspondence between pupil position in the eye-camera image and gaze position on the Display PC monitor. We do this by performing a system calibration, displaying several targets for the subject to fixate. The pupil / CR position for each target is recorded, and the set of target and Pupil-CR positions is used to compute gaze positions during recording.

It is suggested that, if possible, you always calibrate on both eyes. Even if you plan on recording monocularly, calibrating and validating on both eyes allows the system to suggest the best setup single eye for monitoring during the experiment. If you can not calibrate with both eyes select the eye to be used by pressing the “Left” or Right” button in the Eye to Track section of the Camera Setup screen, or by pressing the 'E' key.

There are several possible calibration types available, each of which serves different purpose. By default, a nine-point calibration type (“HV9”) is used. This is good for most of the eyetracking applications. However, if a large calibration region (greater than $\pm 25^\circ$) is involved in an experiment, the “HV13” calibration type should be used for best calibration accuracy. Press the “Set Options” button from the Camera Setup screen to display the Set Options screen. Check to ensure that the following options are selected for practice:

- Calibration type: 9-point grid
- Randomize target order: YES
- Auto-trigger pacing: 1000 msec
- Head tracking: ON

Click the Previous Screen button when done to return to Camera Setup.

Begin calibration by clicking the ‘Calibrate’ button from the Camera Setup menu (C on the Host or display PC keyboard). A calibration target will appear on both the Host PC display and the Display PC monitor. The Display PC image is drawn by the TRACK.EXE application, in response to commands from the EyeLink II system. The Host PC display will also display the raw pupil position as a moving colored circle, and a thresholded eye camera image. A status bar at the bottom-right of the display reports the progress of the calibration.

The pupil-position cursor(s) will jump about when the subject looks about on the display, and will become still when the subject is fixating the calibration target. Instructing the subject to carefully look at the white spot in the middle of the black calibration target will help improve fixation stability. Head movements during calibration should be discouraged: small head movements are corrected, but large movements will severely degrade calibration accuracy, due to distortion of the calibration data pattern and range.

If the cursor jumps continuously and rapidly, or disappears intermittently, the setup for one or both eyes has problems. The eye-movement condition is also visible at the right side of the status bar at the bottom of the Host PC's display.

When the pupil appears stable, accept the first fixation by hitting the ↵ (ENTER) key or spacebar keys or clicking 'Accept Fixation'. The pupil tends to come to rest gradually and to make small vergence movements at the start of the fixation, so do not respond too quickly. However, do not wait too long before accepting the fixation, as subjects soon begin to make involuntary saccades. The proper timing is best learned by watching the gaze cursor during validation (discussed later).

The EyeLink II system helps prevent improper triggering by locking out the ↵ key if the eye is moving. Sometimes the ↵ key will be locked out because of poor eye-camera setup, with the pupil noisy or undetected in some positions. You can use the ⇐ or ⇒ keys on the Host PC keyboard to select the eye camera image to view on-screen and the ↑ and ↓ keys to change the threshold if required. If this fails, or the eye camera needs repositioning, press the 'ESC' key to exit back to the Camera Setup menu.

After the first fixation has been accepted, several more calibration targets are displayed in sequence and fixations for collected each. The EyeLink II calibration system presents these targets in a random order, which discourages subjects from making saccades away from the current target before it disappears.

If automatic sequencing has been enabled, targets will be presented and fixations collected without further intervention. Each time a new target is displayed, the subject quickly makes a saccade to it. The EyeLink II system detects these saccades and the fixation following, producing an automated calibration procedure.

NOTE: Sequencing may halt if the setup of one or both eyes causes pupil loss or noise at the target position. If this happens, adjust the threshold and restart the calibration by pressing the 'ESC' key. Press it twice (once to restart and again to exit) to return to the Setup menu.

Even though the calibration is automatic, watch the Host PC's display carefully. Note the position of the cross-shaped pupil position markers: these should form a grid shape for the 9-point calibration (i.e., they form three parallel horizontal or close-to-horizontal lines and three parallel vertical or close-to-vertical lines; see Figure 3-14). Lapses of subject attention will be clearly visible in the movements of this cursor. Also visible will be any difficulties the subject has in fixating targets, and most eye camera setup

problems.

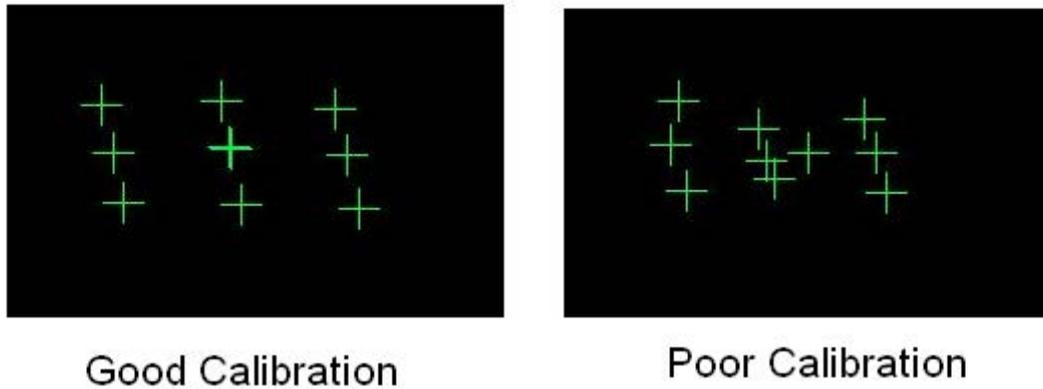


Figure 3-14. Calibration Grid following a Good and Poor Calibration

For some subjects (especially those with neurological conditions) short fixations or lapses of attention can make the automated procedure unusable. A manual calibration mode can be used for these subjects, where the ↵ (ENTER) key must be pressed to collect each fixation. Pressing the 'M' key switches automatic calibration off. It may be switched back on by pressing the 'A' key.

In addition, the "BackSpace" key may be used in the middle of calibration procedure to backtrack the calibration sequence. With each press of this key, the data collected for the last point in the calibration sequence is erased and new calibration data can then be collected. This can be used to improve calibration accuracy for one or few selected points without having to restart the calibration procedure. This is especially helpful for those subjects whose calibration data is hard to get.

When the last calibration target has been presented, the calibration will be evaluated. At the bottom of the Calibration screen, each eye's calibration is graded and displayed as follows: GOOD (green background): No obvious problems found with the data OR FAILED: (red background): Could not use data, calibration must be repeated

The background colour of the message indicates the usability of the calibration. We must still validate the accuracy of the calibration: only serious problems can be detected here. If problems are found, examine the pattern formed by the pupil-position cursors (arrays of crosses) for misplaced or missing fixations. If the calibration was successful, you may press the "Accept" button or the ↵ key to accept the calibration results. Pressing the "Restart" button or the 'ESC' key

will restart the calibration. Pressing 'ESC' twice exits to the Camera Setup screen.

Some users (especially the programmers in the phase of testing experiment programs) may want to run calibration and validation with mouse simulation. To do this, first delete all of the "M*.cal" files in the EYELINK2\EXE directory of the Host PC. Start the EyeLink program, set the "Tracking" option as "Mouse Simulation". Go to the camera setup screen, type 'C'. This will bring up the calibration screen. Press the space bar only once to initiate the calibration process. One or two crosses will be immediately printed on the screen, depending on whether the tracking mode is set to monocular or binocular. In addition, the calibration target and the mouse cursor move to a second calibration point. Press the left mouse button on the Host PC. Click the left mouse cursor for all of the following calibration targets, until the calibration finishes.

The Status Panel will indicate any lapses in collecting data. In normal operation, the indicators are green. Should any of the indicators display a colour other than green, there is a problem with the setup that must be addressed to prevent data loss.

 <p>The screenshot shows a purple box titled 'PUPIL'. Inside, there are two columns. The left column has 'OK' in green, 'SIZE' in yellow, and 'MISSING' in red. The right column has 'OK' in green, 'SIZE' in yellow, and 'MISSING' in red.</p>	<p>Indicates Status of Pupil OK = Pupil is visible SIZE = Pupil is too large MISSING = Pupil is missing</p>
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The pupil status error message "SIZE", highlighted in yellow, indicates that the size of the pupil is too large. To reduce the pupil size the eye-camera must be moved away from the pupil, then refocusing the eye camera lens if needed.

The pupil status error message "MISSING" highlighted in red, indicates that the pupil is missing from the camera view. This could be that the participant is blinking. It could also be that there is a problem with camera setup. Please adjust as needed.

 <p>The screenshot shows a purple box titled 'CORNEAL'. Inside, there are two columns. The left column has 'OK' in green and 'MISSING' in red. The right column has 'OK' in green and 'MISSING' in red.</p>	<p>Indicates Status of Corneal OK = Corneal is visible MISSING = Corneal is missing</p>
--	---

The corneal status error message "MISSING", highlighted in red, indicates that the corneal reflection is not visible to the eye camera. See section 3.6 for details on how to set up corneal reflection properly.

 <p>The screenshot shows a purple box titled 'MARKERS'. Inside, there are two columns. The left column has 'OK' in green, 'MISSING' in red, and 'CONFIG' in red. The right column has 'OK' in green, 'MISSING' in red, and 'CONFIG' in red.</p>	<p>Indicates Status of IR Markers OK = IR-Markers visible to camera. MISSING = at least one IR-Marker is missing from view CONFIG = Extra IR-Marker artifact detected</p>
--	--

For the IR-Markers status error message “MISSING” the IR-Markers are not visible to the head camera. This can be resolved by ensuring the headband is squarely placed on the participants head and that they are directly in-front of the IR-Emitters, which are placed on the corners of the monitor screen in our standard setup.

The error message “CONFIG” means that the EyeLink is detecting too many IR-Emitters. This can be caused by another infra-red source such as sunlight or the eye-camera’s being directed towards the head camera.

All status flags remain on for a minimum of 200 msec, even if the condition that caused the warning or error to be raised lasted for less than 200 msec.

3.8 Validation

It is important that problems with the calibration be identified and corrected before eye-movement recordings are ruined. By running a validation immediately after each calibration, the accuracy of the system in predicting gaze position from pupil position is scored. If performance is poor, the calibration should be immediately repeated.

In a validation, targets are presented on the Display PC monitor in random order, similar to the calibration procedure. When the subject fixates these, the calibration is used to estimate the gaze position of the subject, and the error (difference between target position and computed gaze position) is estimated. Note: since EyeLink II tracker version 2.0, a scaling factor is built in for automatically generated validation point positions to pull in the corner positions (see the ‘validation_corner_scaling’ command setting in the CALIBR.INI file). This is used to limit validation to the useful part of the display.

The gaze-position error comes largely from errors in fixation data gathered during the calibration, although headband slip can add some error. The errors in fixation come from two sources: the eye-tracking system and physiological eye-movement control.

The EyeLink system has extremely low pupil-position noise (typically $<0.01^\circ$ RMS) and very high resolution, and corrects for head motion during calibration and tracking. These common sources of error in the eye-tracking system are virtually eliminated.

One physiological source of calibration inaccuracy is the natural variability in fixation position on targets, estimated at about 0.4° (RMS) for the targets used in this EyeLink demonstration. Vergence eye movements also contribute: these can be seen clearly during validations with binocular gaze position displayed.

For calibrations with 9 targets, it is highly likely that one or more targets will be fixated with an error of 1° or greater. Poor eye camera setup can cause a highly distorted calibration pattern, causing poor head-position compensation and magnifying small errors. Some subjects may show substantial drifts in gaze position during fixations or may not fixate carefully, adding to the errors.

To begin the validation procedure, select the “Validate” button or press the ‘V’ key in the Camera Setup screen. The Host PC’s display will show the gaze position as a round colored cursor, or two cursors in binocular mode. Note the movements of the cursors, and the change in relative horizontal position (vergence) following saccades. Once the cursor appears stable, and close to the \target, press the ↵ (ENTER) key to accept the first fixation. The remaining points are collected automatically or manually, as in the calibration process.

As each fixation is collected, a cross is used to mark its computed position relative to the target. The error (in degrees) is printed next to the cross. Similar to the calibration procedure, the user can use the “Backspace” key in the middle of validation sequence to redo data collection for the last or last few validation points collected. After the final fixation is collected, the average and worst errors are displayed at the bottom of the screen, and the accuracy is scored. Each eye is graded separately, using colored messages similar to the calibration results:

GOOD (green background): Errors are acceptable.

FAIR (grey background): Errors are moderate, calibration should be improved.

POOR: (red background): Errors are too high for useful eye tracking.

Observe the pattern of the errors for each of the targets. If only one target has a high error, the subject may simply have mis-fixated that point, and the validation may be repeated to check this: press ‘ESC’ to return to the Camera Setup screen, and ‘V’ to repeat the validation. If a regular pattern is seen (i.e. all fixations on the left side are too low) there was probably a calibration or camera setup problem. In this case, press ‘ESC’ to return to the Camera Setup screen, and re-calibrate.

If a binocular calibration was performed, the system will automatically select the best eye to record with during the calibration. To accept this selection, press the ENTER key; to override this selection and record in binocular mode, or to select the less accurate eye, make your selection using the mouse and then press the ENTER key to accept your selection. Note, to have the eyetracker always record in binocular mode and not to have it select the best eye, a change in the default settings must be made. Open the FINAL.INI file in the C:\EYELINK2\EXE directory of the Host PC and add the following line:

select_eye_after_validation = NO

Often the computed gaze position shows a systematic shift of all the targets. The average of this bias can be used to correct future gaze-position calculations, lowering tracking error. By accepting the validation the system performs a gaze calculation correction (similar to a drift correction) using this data.

3.9 Improving Calibration Quality

The quality of calibrations determines how useful the data recorded will be and how accurate the gaze calculation will be. Try some of these simple procedures to improve data quality and gaze accuracy:

- Ensure the headband is centered over the subject's nose. There is a centered notch on the bottom of the head camera bar for this purpose. A centered headband will improve head compensation and corneal reflection.
- The corneal reflection should be within the subject's pupil region as much as possible. This will help ensure the corneal reflection is not lost when the subject moves their eyes to the edges of the display.
- The threshold pupil area must be inside the pupil box (displayed as a green box around pupil) when the subject is looking at any area of the display. If a portion of the pupil exits this box, the EyeLink II system will drop to a lower sampling rate until it recovers.
- Give the headband time to settle into place. It may take about 30 seconds for stretched skin under the headband to relax, causing shifts in headband position.
- Be sure the headband cable is hung or clipped so as to have a slack loop behind the head. Cables that hang down to the floor quickly pull the headband out of position, restrict subject head movements, and are subject to damage.
- Subjects who have never been calibrated before require some practice in stably fixating the calibration targets. Try to perform at least two calibrations per subject before beginning to collect data.
- Encourage subjects to sit still! EyeLink II allows moderate head motion, but rapid head or body movements (especially turning the head to look to the side) can cause the headband to shift on the head, and also cause psychophysical gaze-position changes. A subject that doesn't sit still probably is not paying proper attention to the experimental task. A good

chair with a concave seat and back, no wobbling, and the top of the back just below shoulder height will help.

- When writing your own applications, try to match the background color of the screen during calibration and validation to that of the test displays. Changes in pupil size caused by large brightness differences can degrade the system accuracy, especially at the top of the display.
- Perform a drift correction at the start of each experimental trial. If your paradigm does not support this, then perform a drift correction when possible, for example at the start of each block of trials.

3.10 Recording Gaze Position

After the system is set up and calibrated, we can monitor gaze position in real time, and record it for later analysis or viewing. Pressing the “Output” button or the ‘O’ key from the Camera Setup screen will display the Output menu, where eye data files (*.EDF) can be opened and closed, and analog output (if installed) can be controlled. TRACK.EXE automatically opens a data file ‘DATA.EDF’, but you can change this by opening a new file in this menu. Pressing ↵ (ENTER) or ‘O’ again will enter Output mode, and start display of gaze position and data recording.

In this session, we assume the TRACK application is running on the Display PC. When TRACK senses that the Host PC has entered Output mode, it sets up a recording session under its own control.

On the Display PC, it displays a page of text or a target grid on its own screen for the subject to read, alternating between recording sessions. The Host PC screen will show the pattern of boxes that corresponds to each letter or word on the subject’s display. This serves as a reference for the gaze-position cursor displayed by EyeLink II during recording, allowing the operator to see where the subject is looking and detect problems with eye-tracking errors or of subject inattention. Applications can create similar feedback displays by sending drawing commands to EyeLink II before recording begins.

TRACK displays the gaze position as a red cursor on the Display PC monitor. The cursor can be toggled on and off by the ‘G’ key on the Display PC keyboard. To implement this feedback, TRACK requests that EyeLink send it 250 or 500 samples per second of gaze-position via the EyeLink II Windows DLL. This data is used to move the gaze cursor.

TRACK also sends commands to the Host PC to create a data file (DATA.EDF) on the Host PC’s hard disk, which contains samples, fixations, and saccade data.

When the TRACK exits, this file will be automatically transferred from the Host PC to the Display PC. DATA.EDF may be viewed with EyeLink Data Viewer (see the “EyeLink Data Viewer User’s Manual” for information on this optional data analysis tool) or processed with other EDF utilities. Information on the EDF file format can also be found in the Chapter 4 of the current document.

3.11 Drift Correction

In most of the template experiments, a drift correction will be performed at the beginning of each trial. Drift correction works by computing and applying a corrective offset to the raw eye-position data. It is important that before performing a drift correction the subject be instructed to sit still and fixate on the drift correction target carefully. If you need to drift correct very often, it may be worth reviewing how subjects are set up (how well the headband is balanced and fit, the instructions to the subject for calibration, etc) and may repeat a calibration after a certain number of trials.

If your experiment paradigm permits, it is also possible to perform an on-line drift correction in the middle of trial recording by the experimenter. There are two ways of performing an on-line drift correction during recording. If it is very likely that the subject will look at a particular point across trials, a reference position for drift correction could be defined at that position. This can be done by editing the value of “on-line_dcorr_refposn” in the calibr.ini or final.ini file under c:\eyelink2\exe directory of the Host PC or, more preferably, by sending this as a command in your program. When the subject is looking at the reference position, pressing ‘F9’ key on the Host PC or sending an “on-line_dcorr_trigger” command over the link will perform the drift correction.

Alternative, an on-line drift correction can be performed with the aid of a mouse click. Before recording, add the following line to the final.ini file:

```
Normal_click_dcorr = ON
```

This will bring up an additional clickable drift correction button in the Record screen. Click on the “Drift Corr” button, which will flash periodically if enabled. Move the mouse cursor over the intended drift correction target and instruct the participant to fixate the target precisely. Press the button only once when the participant fixates stably. The drift correction may fail if there is no stable fixation data or if there is a large error between the current fixation and the target item. By default, the maximum acceptable error value (set by the ‘on-line_dcorr_maxangle’ command) is 5.0°.



Figure 3-15. Performing an on-line drift correction with mouse click

3.12 Exiting the EyeLink II Host Application

You can now exit EyeLink II. Press the key combination 'CTRL+ALT+Q' from any point in the Host PC tracker program to exit to the command prompt.

3.13 EyeLink II Setup Summary

It is suggested that you try the procedures in this section until you feel comfortable with EyeLink II setup, and can get reliable calibrations.

This is a summary of the steps detailed in the practice session. It assumes no setup problems are encountered.

- Start EyeLink II on the Host PC.
- Start TRACK on the Display PC.
- Fit the subject with the headband, clip cable to subject's collar or suspend it. Adjust forehead position and position the camera bracket bar.
- Press ↵ (ENTER) to start Setup mode, select an eye camera
- Aim the first eye camera, setting distance, height and focus.

- Set the threshold with the 'A' key, and fine-time with ↑ and ↓ keys. Have the subject turn their head to check eye corners.
- Select the second eye camera with ← or →. Repeat setup for this camera
- Check the head camera image for missing markers and position
- Press 'C' to start calibration, press 'ENTER' to collect first fixation, let sequence. Press ↵ to accept result, 'ESC' to repeat.
- Press 'V' to start validation, press ↵ to collect first fixation, let sequence. Press ↵ when finished.
- Repeat calibration if validation is poor
- Press 'O' 'O' to record eye movement data. 'G' on Display PC keyboard toggles gaze cursor on and off.
- Press 'CTRL+ALT+Q' to exit EyeLink II.

3.14 Experiment Practice

The TRACK.EXE program is the most flexible way to practice EyeLink II setup, allowing almost any sequence of actions to be performed. In real experiments, the sequence of actions is much more defined. Usually the experiment begins with subject setup and calibration from the Setup menu, perhaps followed by practice trials and another calibration. Then a series of experimental trials are performed, often with a drift correction before each trial.

This flow allows little room for practice, and makes it important that initial setup and calibration be performed correctly and carefully validated. The EyeLink II tracker has a trial-abort menu built in, which may be used in experiments to terminate trials where setup problems are seen. The Setup menu may then be used to fix eye setup or calibration, and the interrupted trial may be restarted or skipped. This sequence requires co-operation from the experiment application, and example code is given the developer's kit.

3.15 Next Steps: Other Sample Experiments

There are several sample experiments that are valuable demonstrations of how the EyeLink II system can be used and programmed. This section describes each sample experiments purpose and use. For detailed information on the programming / API aspect of these samples, please refer to the EyeLink II Windows Programmers guide. Each sample experiment can be launched from

the Start->Programs -> SR Research EyeLink -> Programming -> Runtime API ->GDI Examples or SDL Examples menu items, and the source are available there as well.

All sample experiments have the following key shortcuts that can be used from the Display PC keyboard. These keys are available after the experiment has started and a Data File name has been entered.

ENTER	View camera or accept Calibration / Validation if Calibration / Validation has just been performed
< or ->	Select Camera
C	Perform Calibration
V	Perform Validation
O	Start experiment
ESC	Abort Trial

A. Simple

The experiment is the most basic EyeLink II sample experiment. The program performs the following steps:

- i. Initialize the EyeLink II library and connect to the EyeLink tracker.
- ii. Create a full-screen window, and sends a series of commands to the tracker to configure its display resolution, eye movement parsing thresholds, and data types.
- iii. Using a dialog box built into the `eyelink_exptkit` library, ask for a file name for an EDF data file, which it commands the EyeLink II tracker to open on the Host PC hard disk.
- iv. Run a block of trials. Each block begins by calling up the tracker's Setup menu screen, from which the experimenter can perform camera setup, calibration, and validation. Four trials are run, each of which displays a single word.
- v. After all blocks of trials are completed, the EDF file is closed and transferred via the link from the EyeLink hard disk to the Windows PC.
- vi. At the end of the experiment, the window is closed and the EyeLink II library is closed.

Each trial begins by performing a drift correction, where the subject fixates a target to allow the eye tracker to correct for any drift errors. Press the space bar to perform the drift correction. Recording is then started. Recording can be stopped by pressing the 'Esc' key on the Windows PC keyboard, the EyeLink Abort menu ('Ctrl' 'Alt' 'A' on the EyeLink keyboard) or by pressing any button on the EyeLink button box.

B. Text

This experiment is an extension of the Simple experiment and uses a slightly more complex process for drawing to the Display PC monitor. For more complex display such as screens of text or pictures, drawing takes too long to complete in one or two display refreshes. This makes the drawing process visible, and there is no clear stimulus onset for reaction time measurement. The code in the “text” template draws to a bitmap (an image in computer memory, not to the display), then copies it to the Display PC monitor, reducing the time to make the display visible. This also has the advantage of making the trial code more general: almost any stimulus can be displayed given its bitmap.

C. Picture

The template “Picture” is almost identical to “Text”, except that images are loaded from BMP or JPEG files and displayed instead of text.

D. EyeData

This template introduces the use of the link in transferring gaze-position data. This data can be used for gaze contingent or gaze control type paradigms. Gaze position data can be transferred in real time, or played back after recording has ended, which helps to separate recording from analysis.

The “Eyedata” template uses link data to display a real-time gaze cursor. The data is then played back after the trial, drawing the saccade paths and fixation points to the screen. The bitmap for the trial is a grid of letters.

E. GCWindow

The most useful real-time experiment is a gaze-contingent display, where the part of the display the subject is looking at is changed, or where the entire display is modified depending on the location of gaze. These require high sampling rates and low delay, which the EyeLink II tracker can deliver through the link.

This template demonstrates how to use the link’s real-time gaze-position data to display a gaze-contingent window. This is an area centered on the point of gaze that shows a foreground image, while areas outside the window show the background image. You supply full-screen sized bitmaps for these, which are stored in the bmp folder. You can use different images by replacing the one provided with the experiment with an image of your own with the same name.

F. Control

This template implements a computer interface that is controlled by the subject’s gaze. The participant can select one of a grid of letters by fixating on it. The template contains code to support many rectangular selection regions, but can be simplified if gaze in a single region is all that needs to be detected. The image for the trial is a grid of letters.

G. Dynamic

This template consists of four experiment blocks. In the first block a red horizontal moving dot is presented which moves from left to right then back again repeatedly. The second block presents a red “/” which moves right to left then changes to “\” when moving left to right repeatedly. The third block presents white dots at three locations along the horizontal axis. The final fourth block presents a white dot, a few seconds later another white dot is shown. The original white dot then fades away. This presentation pattern is repeated.

4. Data Files

The EDF file format is used by the EyeLink II tracker and supporting applications to record eye-movements and other data. It is designed to be space-efficient and flexible, allowing for complete records of experimental sessions and data. It adapts to monocular and binocular recording, with backwards-compatibility for future enhancements. The EyeLink II EDF file format is backwards compatible with the original EyeLink EDF file format. The EDF file format is a platform-portable binary record of eye-position and synchronization events. This format is used directly for EyeLink II applications, and may be translated by the EDF2ASC utility into a text-format ASC file. This file lists most of the important data in the EDF file in a more easily accessible format, but at the expense of much larger file size.

Note: By changing the file data filter from High to Medium or Off, this will affect EyeLink Data Viewer, EDF2ASC, and other analysis tool data calculations.

4.1 File Contents

The EDF files contain two streams of data: eye-position samples (up to 500 per second produced from the EyeLink II tracker) and events (eye-movement events such as saccades and fixations, subject responses, and synchronizing events from the experimental application). Both streams are time-synchronized for easy analysis. The file is organized into blocks of data, one for each recording session. Each block may have samples, events, or both. Also, the data items recorded in each sample or event may be configured at recording, and are available at the block start to aid in analysis.

Samples are time-stamped in milliseconds and contain monocular or binocular eye-position data in eye-rotation angle (HREF) or display-gaze coordinated (GAZE). Pupil sizes as area or diameter are also recordable. Samples may also contain eye-movement resolution (used to compute true velocity or saccadic amplitudes), button presses, or the status of digital inputs.

Eye-movement events record eye position changes identified by the EyeLink II tracker's on-line parser, such as fixations, blinks, and saccades. Both the onset and end of these events are marked, allowing samples to be assigned to eye-movement periods without complex algorithms. Important data for analysis such as average position for fixations and peak velocity for saccades is also recorded in the events. Other events record subject responses (such as button presses) and synchronization and data messages from applications. These can be used to record the time of a change in the display, or an experimental condition.

4.2 Recording EDF Files

EDF files are created by the EyeLink II tracker, recording eye-position data, events from the on-line parser, and button and input events. These are recorded only when the tracker is in output (recording) mode. Messages sent from applications on the Display PC through the Ethernet link may be recorded at any time. Recording EDF files involves opening a data file, recording data from one or more sessions in output mode, and closing the file. These operations can be performed manually using the EyeLink II Host Application on the Host PC, or remotely from the Display PC through the Ethernet.

4.2.1 Recording from the EyeLink II Host PC

In some eye-tracking situations, it is most convenient to initiate the recording of eye movement data directly. For example, displays may be generated by manually-operated equipment, or by non-EyeLink applications. Special provisions must be made for display of the calibration pattern.

By using the EyeLink II tracker's Output Screen, files may be opened and closed, and recording sessions may be started and stopped. Refer to Chapter 2 of this manual "EyeLink II Host Application Operation" for information.

4.2.2 Recording from the EyeLink API

Most eye-movement research involves running many subjects through a sequence of experimental trials, with tens or hundreds of recording blocks per file. This is best done by remote control over the link from an experimental application. The connection from the Display PC to the EyeLink II tracker is implemented by an Ethernet link. Refer to the EyeLink II Programming Manual (Programming EyeLink Experiments in Windows Version 2.0) for details on how to use the EyeLink II API to setup and record EDF files.

4.3 The EyeLink On-Line Parser

The EyeLink II system incorporates a unique on-line parsing system which analyzes eye position data into meaningful events and states (saccades, fixations, and blinks). For many experiments, such as reading or cognitive research, only the events need to be stored in the EDF file, reducing its size by 80% to 95%.

4.3.1 Parser Operation

The parser uses velocity and acceleration-based saccade detection methods. Because of the EyeLink II tracker's exceptionally low noise levels and high spatial resolution, very little data filtering is needed and thus delay is kept small. Typically, the spatial noise is less than 0.005° RMS, allowing a velocity noise level of less than 2°/second RMS to be achieved. The 250 or 500Hz Hz sampling rate gives high temporal resolution of 4 or 2 milliseconds.

For each data sample, the parser computes instantaneous velocity and acceleration and compares these to the velocity and acceleration thresholds. If either is above threshold, a saccade signal is generated. The parser will check that the saccade signal is on or off for a critical time before deciding that a saccade has begun or ended. This check does not affect the recorded time of the saccade start or end, but adds some delay to the real-time events sent through the link.

During each saccade or fixation, data is collected on velocity, position, and pupil size. At the end of the saccade or fixation, this data is used to compute starting, ending, and average position, pupil size and velocity, as well as peak velocity. Velocity data is also converted into units of degrees per second using real-time resolution computed from head camera data. This data is then used to create events which are sent over the link and/or recorded in an EDF file. See the section “*Eye Movement Events*” in the chapter “*Data Files*” for more information on events.

4.3.2 Parser Limitations

The EyeLink II parser was designed for on-line, low delay identification of saccades and blinks. Detection of very small saccades may require off-line processing, as the special filtering and computation of global velocity cannot be performed on-line. In smooth pursuit research, the parser is less sensitive to small back-up saccades (opposite to the direction of pursuit) than forward saccades, due to the low peak velocity of back-up saccades.

The parser only looks “ahead” in the data a short time (8 msec) to compute velocity and acceleration. This limits the data checking the parser can do. Post-processing or data cleanup may be needed to prepare data during analysis. For example, short fixations may need to be discarded or merges with adjacent fixations, or artifacts around blinks may have to be eliminated. Nonetheless, the EyeLink II parser does an excellent job in most recording situations. Adjusting the configuration of the parser may help to bias its performance for specific applications such as smooth pursuit or reading research. Its performance is easily checked: record eye movements using the display of interest, with both sample and event data. Then view the file with EyeLink Data Viewer, to see the correspondence between eye movements and the parser output.

4.3.3 EyeLink Parser Configuration

The saccadic detection parameters for the EyeLink II on-line parser may need to be optimized for the type of experimental investigation being performed. For example, neuro-psychophysical researchers may need to detect small saccades amid pursuit or nystagmus, while reading researchers will need to detect only large saccades and will want fixation durations maximized. This section explains the function of, and suggests values for, the most useful parser parameters.

Some experimentation may be required to select the best parameters. If an EDF file has been recorded with full sample data, it can be reprocessed by the EyeLink II tracker, allowing the parser configuration in PARSE.INI to be fine-tuned. The eye-movement data can then be viewed with EyeLink Data Viewer with saccades and blinks overlaid, to confirm the parsing accuracy. Once correct parameters are determined, they can be set by EyeLink II commands over the link as part of the experimental setup, or the EyeLink II configuration file PARSE.INI can be edited to change the default parameters.

4.3.4 Parser Data Type

Three eye-position data types are available from the EyeLink II tracker for each sample: raw pupil position, head-referenced angle, and gaze position (see the chapter “File Data Types” for more information). The parser can use any one of these for detecting saccades and generating data for events.

The parser data type is set by the EyeLink command “`recording_parse_type`”. It can be changed by editing the configuration file PARSE.INI, or by sending a command over the link. The text of the command is one of:

```
recording_parse_type = GAZE
recording_parse_type = HREF
recording_parse_type = PUPIL
```

4.3.5 Saccadic Thresholds

Three thresholds are used for saccade detection: motion, velocity, and acceleration. The values of these are in degrees, degrees/sec, and degrees/sec² respectively.

The velocity threshold is the eye-movement velocity that must be exceeded for a saccade to be detected. A velocity threshold of 22 degrees per second allow detection of saccades as small as 0.3°/sec, ideal for smooth pursuit and psychophysical research. A conservative threshold of 30°/sec is better for reading and cognitive research, shortening saccades and lengthening fixation durations. The larger threshold also reduces the number of microsaccades detected, decreasing the number of short (less than 100 msec in duration) fixations in the data. Some short fixations (2% to 3% of total fixations) can be expected, and most researchers simply discard these.

Use of eye-movement acceleration is important for detection of small saccades, especially in smooth pursuit. Acceleration data has much more noise than velocity data, and thresholds of 4000°/sec² for small saccade detection and 8000°/sec² for reading and cognitive research are recommended. Lower acceleration thresholds will produce false saccade reports. Acceleration data and thresholds for the EyeLink II system may be larger than those reported for analog eye trackers. These systems use multi-pole filters for noise reduction that adds delay and smoothes the data, significantly reducing the measured acceleration.

The saccadic motion threshold is used to delay the onset of a saccade until the eye has moved significantly. This can add 4 to 8 msec to the reported duration of fixations in cognitive research. A threshold of 0.1° to 0.2° is sufficient for shortening saccades. Larger values may be used with caution to eliminate short saccades: for example, a threshold of 0.4° will always merge fixations separated by 0.5° or less, but may eliminate some 1° saccades as well. The threshold should be set to zero for non-cognitive research, or where statistics such as saccadic duration, amplitude and average velocity are required.

Examples of the commands to set these thresholds are:

```
saccade_velocity_threshold = 30
saccade_acceleration_threshold = 8000
saccade_motion_threshold = 0.15
```

4.3.6 Pursuit Thresholds

During smooth pursuit and nystagmus, saccades must be detected against a background of smooth eye motion as fast as 70°/sec. While acceleration can be used to detect these saccades, velocity data must also be used for reliable detection of all saccades. The EyeLink II parser raises the saccadic velocity threshold during pursuit by the average velocity over the last 40 milliseconds. This is reliable, and does not degrade parser performance during non-pursuit eye movements.

During long saccades such as the return sweep in reading, this fix up causes the saccadic velocity threshold to be raised. This is not a problem as long as the adjustment is limited, as it helps to prevent prolongation of these saccades by overshoots and glissades. The pursuit threshold limits the amount that the saccadic threshold can be raised. A limit of 60°/sec works well for most pursuit and other research, but may have to be raised if very rapid pursuit or nystagmus is being recorded.

The limit is set in degrees per second. An example of this command is:

```
saccade_pursuit_fixup = 60
```

4.3.7 Fixation Updates

Monitoring eye position or pupil size during fixations usually requires processing all samples produced by the tracker. This is acceptable for file data, but is expensive for real-time systems using data sent via the link. Fixation updates solve this problem by sending updates on eye position, pupil size, velocity etc. at regular intervals during a fixation. The first update is sent one update interval after the start of the fixation, and the last is sent at the end of the fixation. Data is aggregated over a preset period, which lowers data noise. The interval between updates and the data accumulation period can both be set.

Fixation updates are most useful for real-time display paradigms. In some studies, the subject is required to fixate a target while stimuli are presented. Fixation updates can be used to check gaze position every 100 msec or so. Computer interfaces operated via eye movements is a paradigm dramatically simplified by fixation updates. Actions are triggered by gaze on an active area of the screen for a critical duration. This is implemented simply by counting sequential fixation updates that fall within the area.

Two commands set the fixation update interval and data accumulation period in milliseconds. Usually these are set to the same value. An interval of zero disables fixation update. An update interval of 50 or 100 msec is a good choice:

```
fixation_update_interval = 100
```

```
fixation_update_accumulate = 100
```

4.3.8 Other Parameters

The EyeLink II PARSER.INI configuration file contains other commands that configure the parser. These are of several types:

- Verification delays. These set the time in milliseconds that the parser requires a detector output (saccadic velocity or acceleration thresholds, or missing pupil for blink) to be stable before the parser changes its state and sends events to the data file or link. These values have been determined empirically, and there is little advantage to changing them.
- Parser filter types. Two velocity filters are available: fast and slow. The fast filter works better in most cases. The slow filter is less noise sensitive, but increases saccade duration and decreases sensitivity slightly.
- Saccade extension. This is intended to allow the saccade period to include the lower-velocity start and end of the saccadic period. This is usually disabled, as its effect is minor.
- Internal constants. These MUST NOT be changed.

4.3.9 Sample Configurations

The complete set of commands for the most useful tracker configurations is given below. The cognitive configuration is conservative, is less sensitive to noise and ignores most saccades smaller than 0.6°. The psychophysical configuration is useful for neurological and smooth-pursuit research, and reports very small saccades. It also better estimates saccade durations and average velocities.

Cognitive Configuration:

```
recording_parse_type = GAZE
```

```
saccade_velocity_threshold = 30
```

```
saccade_acceleration_threshold = 8000
```

```
saccade_motion_threshold = 0.15
```

```
saccade_pursuit_fixup = 60
fixation_update_interval = 0
```

Psychophysical configuration:

```
recording_parse_type = GAZE
saccade_velocity_threshold = 22
saccade_acceleration_threshold = 4000
saccade_motion_threshold = 0.0
saccade_pursuit_fixup = 60
fixation_update_interval = 0
```

4.4 File Data Types

The data contents of an EDF file are organized in two streams: samples and events. Samples are used to record instantaneous eye position data, while events are used to record important occurrences, either from the experimental application of from changes in the eye data.

Both samples and events can report eye data in several forms. These are discussed in the description of sample data. Eye movement data is parsed by the EyeLink II tracker on-line and used to generate eye-movement events, which are discussed with application messages and button events.

4.4.1 Samples

Samples are records of eye-position, pupil size, and button or input states. The EyeLink II tracker can record up to 500 samples per second, from one eye (monocular) or both eyes (binocular). Each sample is stored as a binary record in the EDF file, with simple compression used to minimize disk space. Even with compression, recording 500 samples per second binocularly will create very large data files: about 4K to 10K of data per second.

Each sample may contain several data field, including:

- Time of the sample (timestamp) in milliseconds
- One or more types of eye position data, monocular or binocular
- Pupil size, monocular or binocular
- Angular resolution of eye-position data
- Button or input port state bits

All samples contain a timestamp, recorded in milliseconds. The time is measured from the time when the tracker software was started. This

timestamp makes detection of missing samples possible, as well as simplifying processing of data. Usually all samples produced by the EyeLink II tracker are recorded, but the tracker may be configured to record samples at a lower rate, or only when significant changes in eye position occur. These special modes are not used for most data, as they may prevent re-analysis of the EDF file. Other types of sample data are discussed in greater detail below.

4.4.2 Position Data

Eye position data is produced by the EyeLink II tracker for one or both eyes every 2 or 4 milliseconds depending on the tracking mode and speed set. It is then processed to compute eye rotation angles and to compensate for subject head motions. The processed data in one or all of these forms may be recorded in the samples. Data is written as (x, y) coordinate pairs, or two pairs for binocular data. The types of position data available are explained below.

4.4.2.1 PUPIL

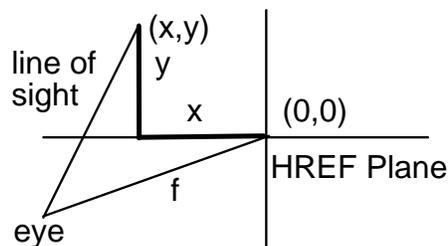
Pupil position data is raw (x, y) coordinate pairs from the eye cameras. It has not been converted to eye angles or to gaze position. There may be a non-linear relationship between this data and true gaze position. Pupil position is reported in integer values, with 200 to 400 units per visual degree.

When a calibration has not been performed, the EyeLink system cannot convert pupil data to the more useful data types. Raw pupil position is useful when auto-sequencing calibrations, or when the application wishes to perform its own calibration. Most users will not need this data type.

4.4.2.2 HREF

The HREF (head-referenced) position data directly measures eye rotation angles relative to the head. It does not take into account changes in subject head position and angle, or distance from the display. However, it may be more accurate for neuro-psychophysical research, as it reflects real eye movement velocities and amplitudes.

The (x, y) coordinate pairs in HREF data reflect the line of sight in the geometric model below:



The (x,y) positions define a point in a plane at distance f (15000 units) from the eye. The HREF units are independent of system setup, display distance, and display resolution. The HREF coordinates are reported in integer values, with 260 or more units per visual degree.

The (0, 0) point in the coordinate system is arbitrary, as the relationship between display positions and HREF coordinates changes as the subject's head moves. Even when a chinrest is used to stabilize the subject's head, head rotations of several degrees can occur. HREF coordinates are best used for determining angles relative to a known eye position, or to measure eye-movement velocities, as described below.

The eye rotation angles may be directly computed from the HREF (x, y) pairs. There are several methods of specifying eye-rotation angles. The angular distance (eye rotation magnitude) between any two HREF points is directly computable. The C code to compute this angle is given below. Remember to multiply the result by 57.296 to get the angle in degrees.

angle = acos((f*f + x1*x2 + y1*y2) / (sqrt((f*f + x1*x1 + y1*y1) * (f*f + x2*x2 + y2*y2)))); The HREF angular resolution may be computed as the first derivative of the rate of change of HREF position with angle. It is sufficient to compute the resolution separately for the x and y coordinate directions. This may be used to compute true eye-movement velocities, by dividing computed velocity in HREF units by the resolution for the sample. These formulas give the x and y resolution in units of change in HREF position per degree of visual angle:

```
xres = 0.01745 * (f*f + x*x + y*y) / sqrt(f*f + y*y);  
yres = 0.01745 * (f*f + x*x + y*y) / sqrt(f*f + x*x);
```

4.4.2.3 GAZE

Gaze position data reports the actual (x, y) coordinates of the subject's gaze on the display, compensating for head position changes and distance from the display. The units are in actual display coordinates (usually pixels) which can be set in the EyeLink II configuration file PHYSICAL.INI. These are the most useful coordinates for most applications, but may not reflect true eye-rotation velocities due to head movements. The default EyeLink II coordinates are those of a 640 by 480 VGA display, with (0, 0) at the top left.

The resolution data for gaze position data changes constantly depending on subject head position and point of gaze, and therefore is reported as a separate data type (see below). A typical resolution is 22 pixels per degree for the suggested EyeLink II setup, with the distance between the subject's eyes and the display being twice the display's width, and with the standard 640 by 480 screen resolution.

The high resolution of the EyeLink II data is preserved by multiplying the position by a prescaler, recording the value as an integer in the EDF file, then dividing by the prescaler when the file is read. The usual prescaler value is 10, allowing gaze position to be recorded with 0.1 pixel of resolution or a resolution of 0.0045 degree. Actual EyeLink II resolution is limited only by measurement noise, which is less than 2 units RMS (0.01 degree, or 40 seconds of arc) in pupil only mode and approximately 4 units RMS (0.022 degree, or 88 seconds of arc) in pupil-corneal reflection mode.

4.4.2.4 Gaze Resolution Data

For gaze position, unlike the HREF data, the relationship between visual angle and gaze position is not constant. The EyeLink II tracker computes and can record the instantaneous angular resolution at the current point of gaze. This is measured as the units (usually pixels) per degree of visual angle, computed for a change in x and y position separately.

This resolution data may be used to estimate distances between gaze positions, and to compute velocities of eye movements. To compute the angular distance of two points, compute the x and y angular distances of the points separately by dividing the distance in pixels by the average of the resolutions at the two points, then compute the Euclidean distance from the x and y distances. For instantaneous velocity in degrees per second, compute the x and y velocities, then divide each by the x or y resolution, square and add the x and y velocities, and take the square root.

As noted above, typical resolution is 22 pixels per degree. Resolution is computed at the point of gaze on the display, and can vary up to 15% over the display. The resolution data in an EDF file is recorded using a prescaler for extra precision, and noted in the gaze-position section).

4.4.3 Pupil Size Data

Pupil size is also measured by the EyeLink II system, at up to 500 samples per second. It may be reported as pupil area, or pupil diameter. The pupil size data is not calibrated, and the units of pupil measurement will vary with subject setup. Pupil size is an integer number, in arbitrary units. Typical pupil area is 800 to 2000 units, with a precision of 1 unit, while pupil diameter is in the range of 1800-3000 units. Both measurements are noise-limited, with noise levels of 2-10 units RMS. This corresponds to a resolution of 0.015 mm for a 5 mm pupil.

Pupil size measurements are affected by up to 10% by pupil position, due to the optical distortion of the cornea of the eye, and camera-related factors. If research using pupil size is to be performed, the subject should not move their eyes during the trials. They can be presented with a fixation point with aural stimulus presentation, or a single stimulus position at display center may be used. It is also possible to counterbalance stimulus position during the experiment.

4.4.4 Button Data

The state of up to 8 buttons or input port bits may be recorded in each sample. Button ports, bits, and polarity may be set in the EyeLink II tracker configuration file `BUTTONS.INI`.

The button data consists of two 8-bit fields, recorded as a 16-bit number. The lower 8 bits contain the current status of the 8 buttons (bit = 0 if off, 1 if pressed). Each of the upper 8 bits will be set to 1 if its button has changed

since the last sample. The least-significant bit in each byte corresponds to button 1, and the most-significant to button 8.

4.5 Events

One of the most significant aspects of the EyeLink II tracking system and the EDF file format is its on-line processing of eye-movement data to identify and record events such as fixations and saccades. This eliminates the need for recording of sample data for many types of research, and achieves a data compression of 20:1 or greater. Samples need only be recorded for data validation or if sample-by-sample eye position or velocity is required. Events can record application data such as the time of a display change and experimental conditions, or real-time events such as button presses. Events also define the start and end of blocks of data in the EDF file, allowing applications to process data recorded with different data types.

Each event contains one or two timestamps (in milliseconds) and several data fields. Data for each event is compressed, and an extendable data format allows compatibility with future expanded file formats.

Note that not all the event data listed here is available through the EDF2ASC translator program.

4.5.1 Messages

The most flexible event type is the message event. A message is most often text, but can contain any type of binary data as well, up to a maximum of 300 bytes. Messages are created by application software, and forwarded over the link to the EyeLink tracker, which timestamps the data and writes it to the EDF file. The application does not need precise timekeeping, since link delays are usually very low (on the order of 1 or 2 milliseconds).

Message events are used for two main purposes. They serve to precisely record the time of important events, such as display changes, subject responses, etc. They also record experiment-specific data, such as trial conditions.

Message events consist of a millisecond timestamp, and the message data. A message is most often text, but can contain any type of binary data as well. For text data, a zero byte at the end of the text is recommended for compatibility with applications written in C. A message data length field provides Pascal string compatibility, and allows binary data to be recorded in the message. Current EyeLink applications only support text messages with zero-terminated strings. It is also recommended that messages be shorter than 250 characters.

4.5.2 Buttons

Each button event records a change in state (pressed or released, 1 or 0) of up to 8 buttons or input port bits, monitored by the EyeLink II tracker. Button

ports, bits, and polarity may be set in the EyeLink II tracker configuration file `BUTTONS.INI`.

Each button event contains a timestamp (in milliseconds) of the time the button was pressed, and a word of button data. This consists of two 8-bit fields, recorded as a 16-bit number. The lower 8 bits contain the current status of the 8 buttons (bit = 0 if off, 1 if pressed). Each of the upper 8 bits will be set to 1 if its button has changed since the last sample. The least-significant bit in each byte corresponds to button 1, and the most-significant is button 8.

Button events are usually recorded at the start of each recording block, with all upper 8 bits (change flags) set to 0. This allows applications to track the current button state at all times.

4.5.3 Eye Movement Events

Events are generated by the EyeLink II tracker in real-time from the eye-movement data stream. These provide an efficient record of the data in a form ready to use for most types of eye-movement research. The use of events simplifies the analysis of sample data as well. For example, analysis of pursuit gain requires rejection of saccades, which are clearly marked in the events. Eye-movement events are generated in pairs: one event at the start of an eye-movement condition, and another at the end of the condition. When used in real-time processing with data set via the link, the event pairs allow an application to monitor eye movement state in real time. These pairs accurately label the samples in a file between the events, as the file is read from beginning to end.

Eye-movement events are always labeled by which eye generated the event. If binocular data is recorded, a separate start and end event is generated for each eye. The time differences between eyes are very important for neurological analysis, for example.

Start events contain the time of the start of the eye-movement condition. They may also contain the state of the eye at the onset of the condition: for example, the position and pupil size at the start of a fixation.

End events contain both the start and end time of the condition. The end time is actually the time of the last sample in the condition, so length of a condition must be computed as the difference between the end and start times plus the time between samples (2 or 4 milliseconds). End events also contain summary data on the condition as well: average gaze position of a fixation, for example. The main classes of data events are summarized below.

4.5.3.1 Record Blocks

Each block of recorded data in an EDF file begins with one or both of a `STARTSAMPLES` or `STARTEVENTS` event. These contain the time of the recording start, and specify what data can be expected to follow. This allows

flexible applications to adapt to almost any file-data configuration. Information included in the start events include:

- Which eye(s) recorded from
- Sample data rate
- Sample data contents
- Event data contents
- Event types included
- Gaze-position and velocity prescalers

Each block of recorded data ends with one or both of an ENDSAMPLES or ENDEVENTS event. This simply terminates the data block, and specifies the time that recording ended.

The text files generated from EDF files by the EDF2ASC translator utility create a simplified form of START and END events. A single START or END line is produced for both sample and event blocks, which specifies which eye(s) were recorded from, and whether samples, events, or both, are present in the following data block. Other data is given on following SAMPLES, EVENTS, PRESCALER, etc. lines.

4.5.3.2 Fixations

The on-line EyeLink II tracker parser processes eye-position data, identifying saccades and fixations and compiling data on these conditions. For fixations, these data include:

- The time of the first and last sample in the fixation
- The eye that generated the event
- Start, end, and average HREF and gaze position data
- Start, end, and average pupil size
- Start, end, average, and peak eye-movement velocity
- Start and end gaze-data angular resolution

All of this data may appear in the ENDFIX event that terminates the fixation. Only the starting data can appear in the STARTFIX event that initiates the fixation.

In a sorted EDF file or a text ASC file (produced by EDF2ASC) that contains both samples and events, the STARTFIX event will precede the first sample in the file that is part of the fixation, and the ENDFIX event will follow the last sample in the fixation. This allows the sample data in the files to be processed by saccade or fixation in a single pass.

The data contained in STARTFIX and ENDFIX events may be configured by modifying the DATA.INI file for the EyeLink II tracker. For most research, only simple fixation statistics are required, such as average position and pupil size. STARTFIX events may also be configured to contain only the start time of the fixation.

Other data in the ENDFIX event may be useful for some types of analysis. The start and end position may be used to measure drift or pursuit during the fixation. The resolution may be used to estimate angular distance between fixations. Subtract the x and y position data for the fixations, divide by the average corresponding resolution data, and compute the Euclidean distance:

```
dx = (x1 - x2) / ((rx1 + rx2)/2.0);  
dy = (y1 - y2) / ((ry1 + ry2)/2.0);  
dist = sqrt(dx*dx + dy*dy);
```

The velocity data for fixations tends to be biased by the initial and terminal portions of the saccades that precede and follow it. Average velocity is more reliable.

4.5.3.3 Fixation Updates

Data within a fixation can be broken into smaller time segments, useful for real-time analysis and control via eye movements. FIXUPDATE events may be produced at regular intervals within a fixation, and contain data for a specified length of time within the fixation. The data recorded in the FIXUPDATE event is similar to that in the ENDFIX event.

FIXUPDATE events are most useful in real-time applications using the link. Recording samples in the EDF file is more useful for most psychophysical research.

4.5.3.4 Saccades

The EyeLink II tracker's parser detects saccades by the velocity and acceleration of the eye movements. It can reliably detect saccades as small as 0.3 degrees. Because of variations in acceleration profiles, the onset and offset point of saccades can vary by one or two samples from "ideal" segmentation done by hand. Nonetheless, the saccadic data compiled by the parser is sufficient for most neuro-psychophysical research, including smooth pursuit. Most cognitive research will ignore the saccadic data, using the fixation data produced by the EyeLink II parser. The saccadic data produced for saccades includes:

- The time of the first and last sample in the saccade
- The eye that generated the event
- Start, end, and average HREF and gaze position data
- Start, end, and average pupil size
- Start, end, average, and peak eye-movement velocity
- Start and end gaze-data angular resolution

All of these data may appear in the ENDSACC event that terminates the fixation. Only the starting data can appear in the STARTSACC event that initiates the fixation.

In a sorted EDF file or a text ASC file (produced by EDF2ASC) that contains both samples and events, the STARTSACC event will precede the first sample in

the file that is part of the fixation, and the ENDSACC event will follow the last sample in the fixation. This allows the sample data in the files to be processed by saccade or fixation in a single pass. The data contained in STARTSACC and ENDSACC events may be configured by modifying the DATA.INI file for the EyeLink tracker. Saccadic events may be eliminated entirely, if only fixation data is required. STARTSACC events may also be configured to contain only the start time of the fixation.

The peak and average velocity data for saccades is especially valuable for neuro-psychophysical work. These are the absolute velocities measured as the Euclidean sum of x and y components. The EyeLink II parser computes velocity by use of a 5-sample moving filter, which is equivalent to a differentiator followed by a 2-sample moving average, or a 63 Hz single-pole filter. This is optimal for detection of small saccades, minimizes extension of saccade durations, and preserves saccadic peak velocities.

Other data in the ENDSACC event may be useful for some types of analysis. The start and end position, and start and end resolution, may be used to compute saccadic amplitude. This is more easily done by multiplying average velocity by the saccadic duration:

```
dist = 1000.0 * (end_time - start_time + 4.0) * avg_velocity;
```

In general, the saccadic amplitude will be slightly less than the distance between average position of the preceding and following fixations, as saccades do not include sub-threshold velocity parts of the eye movement that precede and follow the rapid phase.

4.5.3.5 Blinks

The STARTBLINK and ENDBLINK events bracket parts of the eye-position data where the pupil size is very small, or the pupil in the eye-camera image is missing or severely distorted by eyelid occlusion. Only the time of the start and end of the blink are recorded.

Blinks are always preceded and followed by partial occlusion of the pupil, causing artificial changes in pupil position. These are sensed by the EyeLink II parser, and marked as saccades. The sequence of events produced is always:

- STARTSACC
- STARTBLINK
- ENDBLINK
- ENDSACC

Note that the position and velocity data recorded in the ENDSACC event is not valid. All data between the STARTSACC and ENDSACC events should be discarded. The duration of the blink may be computed by either the duration of

the missing pupil between the STARTBLINK and ENDBLINK events, or the difference between the ENDSACC and STARTSACC events in the sequence. Fixation immediately preceding and following blinks should be examined carefully, as they may have been truncated or produced by the blink process. Discarding fixations shorter than 100 ms preceding or following blinks will eliminate most artifacts.

4.6 Setting File Contents

The data recorded in samples and events may be set in the EyeLink II configuration file DATA.INI, or by sending commands to the tracker across the link, via the API `eyelink_timed_command()`. Similar commands exist for samples and events sent over the link for real-time applications.

4.6.1 Sample Data

The sample data written to the EDF file is controlled by the "file_sample_data" command, which is followed by a list of data types to include. A single keyword is included for each type:

Keyword	Data Type
LEFT, RIGHT	limits data to one or both eyes (usually include both LEFT and RIGHT)
GAZE	includes screen gaze position data
GAZERES	includes units-per-degree screen resolution at point of gaze
HREF	head-referenced eye position data
PUPIL	raw eye camera pupil coordinates
AREA	pupil size data (diameter or area)
BUTTON	buttons 1-8 state and change flags
STATUS	warning and error flags (not yet supported)
INPUT	input port data lines (not yet supported)

The default data is:

```
file_sample_data = LEFT,RIGHT,GAZE,GAZERES,AREA,STATUS
```

Usually, data for both eyes is enabled, and the menus in the EyeLink II tracker are used to set which eye(s) are used. Recording of gaze and pupil area is essential for most work, and resolution is important if velocity is to be computed later. Recording of HREF data is optional.

4.6.2 Event Data

Eye-movement events are generated by processing one of the types of eye movement data (PUPIL, HREF, or GAZE) as specified by the "recording_parse_type" command. This command may be edited in the PARSER.INI file of the EyeLink II tracker, or may be sent over the link.

```
recording_parse_type = <data type: one of PUPIL, HREF, or GAZE>
```

The data type used for parsing will always be included in the event data. Other data reported for eye-movement events are controlled with the "file_event_data" command. This is followed by a list of data types and options, selected from the list below:

Keyword	Effect
GAZE	includes display (gaze) position data.
GAZERES	includes units-per-degree screen resolution (for start, end of event)
HREF	includes head-referenced eye position
AREA	includes pupil area or diameter
VELOCITY	includes velocity of parsed position-type (average, peak, start and end)
STATUS	includes warning and error flags, aggregated across event (not yet supported)
FIXAVG	include ONLY averages in fixation end events, to reduce file size
NOSTART	start events have no data other than timestamp

The "file_event_data" command may be edited in the PARSER.INI file of the EyeLink II tracker, or may be sent over the link. Some example settings are given below:

GAZE,GAZERES,AREA,HREF,VELOCITY	- default: all useful data
GAZE,GAZERES,AREA,FIXAVG,NOSTART	- reduced data for fixations
GAZE,AREA,FIXAVG,NOSTART	- minimal data

4.6.3 Event Types

The "file_event_filter" command specified what type of events will be written to the EDF file. It may be changed in the PARSER.INI file of the EyeLink II tracker, or may be sent over the link. The command is followed by a list of data types and options, selected from the list below:

Keyword	Effect
LEFT, RIGHT	limits data to one or both eyes (usually include both LEFT and RIGHT)
FIXATION	includes fixation start and end events
FIXUPDATE	includes fixation (pursuit) state update events
SACCADE	includes saccade start and end events
BLINK	includes blink start and end events
MESSAGE	includes messages (ALWAYS use)
BUTTON	includes button 1..8 press or release events
INPUT	includes changes in input port lines (not yet supported)

These examples of the command are the default event set, and a fixation-only configuration:

```
file_event_filter= LEFT,RIGHT,FIXATION,SACCADE,BLINK,MESSAGE,BUTTON
```

```
file_event_filter = LEFT,RIGHT,FIXATION,BLINK,MESSAGE,BUTTON
```

4.7 EDF File Utilities

A number of utility programs are included in the EyeLink II package, to process and view EDF files. The utility EDF2ASC translates EDF files into text ASC files for processing with user applications.

4.7.1 EDFSCAN

The EDFSCAN utility will scan and summarize the data contents of one or more EDF files, listing the recording blocks and types of data it contains. It will also check for file errors that may indicate a corrupt file. The command line format of EDFSCAN is:

```
edfscan <input .edf file> [<optional log file>]
```

The input EDF file name can contain a path to a new directory, or wildcards (* and ?) to allow processing of multiple files. If more than one file matches the input EDF filename, you will be for each file on whether to process it, process all file, skip it, or stop processing. The optional log file (extension .LOG) will record all the text printed to the screen, making documentation of large sets of EDF files easier. For each file scanned, the following data is listed:

File Name	File scanned
Preamble	Text at the start of file that can be read with a text editor. It reports file version, data created, and any description from the application
Blocks	Recorded blocks of samples or events, with number of samples and events, duration, number of fixations and blinks, and any file errors.
Total Duration	Total time covered by file, with percentage of time recorded as blocks
Fixations	Total fixations, with number of exceptionally short (<100 msec) and long (>1500 msec)
Events	Count of messages, saccades, blinks, button presses
Samples	Total recorded samples, count of missing data gaps
Resolution	Average angular resolution of gaze data (pixels per visual degree)
Ordering	UNSORTED message if file needs sorting

During file scanning, error or warning messages may be generated. Any non-error messages may be safely ignored. Error messages indicate serious file structure problems, and will terminate processing of the file.

You may also control what is reported to you. Normally, only serious errors and missing samples are reported. By adding the “-v” option to the command line, you may also view warnings and data on each recording block in the file.

4.8 Using ASC Files

The EDF file format is an efficient storage format for eye movement data, but is relatively complex to support. To make the data in EDF files accessible, the

translator EDF2ASC converts the files into a text version that is easily accessible from almost any programming language.

The ASC file format consists of lines of text, with each line containing data for a single sample, event or data parameter. It is easily read, and is ordered to make most data-processing tasks straightforward. Many translation options are available, specifying the file contents.

4.8.1 EDF2ASC

The EDF2ASC utility reads one or more EDF files, creating text files with the same name but with the ASC extension. It scans the input file, reordering data as required, and converting samples and events into lines of text. It can also compute resolutions and instantaneous velocity for sample data. The ASC file are about twice as large as the original EDF files.

To translate an EDF file, type "EDF2ASC" followed by the name of the file to be translated and any conversion options. Wildcards (* and ?) may be used in the input file name, allowing conversion of multiple EDF files to ASC files with the same name. Optionally, a second file name can be specified for the output ASC file. Many options exist for the file conversion. One set of options will be best for your work, and creation of a single-line batch file (called, for example, E2A.BAT) will make the use of the translator easier.

4.8.2 Translator Options

The options for EDF2ASC are of 4 types: file selection, sample data, event type, and general data. These are discussed below, and then summarized in a table at the end of the section.

4.8.2.1 File Selection

File names for EDF file inputs are specified with the first filename on the command line. This may have wildcards (* and ?) to specify a set of files. If more than one file matches the specification, EDF2ASC will prompt for each file name. Press 'Y' to process the file, 'N' to skip it, 'A' to process all remaining files, and 'Q' to skip all files.

If a second file name is present in the command line, it will be used to name the output file. Otherwise, the output file will have the same name as the input file, with the extension ASC added. This is the default mode if multiple files are to be translated. By using the "-p" option, a destination directory or alternative file extension can be specified. The translation of each file may be logged by creating a list file with the "-d" option. This is useful for recording multiple-file batch conversions.

Some translation examples are:

EDF2ASC trial1	translates "trial1.edf" to "trial1.asc"
EDF2ASC trial1 trial1a	translates "trial1.edf" to "trial1a.asc"
EDF2ASC trial*	translates "trial1.edf", "trial2.edf" etc. to "trial1.asc", "trial2.asc" etc.
EDF2ASC trial* -p asc	translates "trial1.edf" etc. to "asc\trial1.asc" etc. (in "asc" subdirectory)
EDF2ASC trial* -p *.dat	translates "trial1.edf" etc. to "trial1.dat" etc. (uses "dat" extension)
EDF2ASC trial* -d trial	translates "trial1.edf" etc. to "trial1.asc" etc., logs to "trial.lst"

4.8.2.2 General Data

An EDF file may contain eye movement data in many types of data, especially if the default EyeLink II recording parameters are used. For example, both left and right eye data may be present, with only one eye's data used in analysis. Eye position may be recorded in both gaze and HREF (angular) formats. Both samples and events may be recorded, with only events needed for analysis and samples for graphical viewing only. By default, EDF2ASC translates all samples and events, using gaze-position data only. Using the command-line options listed below allows the data present in the ASC file to be controlled.

To select one eye's data (both samples and events) from a binocular data file, specify left or right eye data with "-l" or "-r" respectively. These are ignored for monocular data files. The options "-nr" (no right) and "-nl" (no left) limit monocular data as well, and can result in all eye-movement data being removed.

Samples may contain several types of eye position data. Only one of these types may be output in the ASC file. The desired data type is specified by "-sg" for gaze-position data (the default), "-sh" for HREF data, and "-sp" for raw pupil-position data. If the desired data type is not present in the file, a warning message will be logged and another data type will be used.

The type of position data reported for eye-movement events (saccades and fixations) is determined by the type of eye-position data that was used in parsing the data in the EyeLink II tracker. This is set with the "recording_parse_type" command.

Resolution and instantaneous velocity data may be included for sample data lines, as well as events. Resolution data is included if the "-res" option is specified, and velocity data is included by the "-vel" option. Resolution data reported will match the type of eye-position data in the file. Gaze-position resolution (in units of pixels per visual degree) is computed by the EyeLink II tracker, and must be recorded in the EDF file as it cannot be computed. No resolution data is available for raw pupil-position data. Resolution for HREF data is determined by the position itself, and is computed by the EDF2ASC translator.

Velocity data in saccade and fixation events is reported directly if the "-vel" option is present. For samples, the velocity is computed from the position and resolution data using the same processing used in the EyeLink II tracker. Velocity for gaze-position data cannot be computed unless gaze-resolution data is also present.

4.8.2.3 Sample and Event Selection

The size and readability of the translated ASC file is controlled by selecting the types of events or samples present. The presence of samples increases file size by a factor of 10 or 20, compared to events alone. Eliminating all samples and eye-movement events makes the basic structure of the data file apparent, aiding design of analysis software.

By default, both samples and events are translated into the output ASC file. Samples may be eliminated with the "-e" (events only) or "-ns" (no samples) options. All events may be eliminated with the "-s" (samples only) or "-ne" (no events) options. This results in a file containing only sample data lines, with no events, comments, or file structure lines.

More selective event filtering is possible. With the "-nse" (no start events) option, only summary events (end of fixations, saccades, or blinks) are reported, which halves the number of eye-movement events and may be acceptable for hand analysis or simple cognitive experiments. All eye-movement events may be removed with the "-neye" (no eye) option, resulting in a listing of file messages and data blocks. This is useful as a summary of file structure when designing analysis software for experiments. Finally, message events can also be removed with the "-nmsg" (no messages) option.

Examples of the most useful sets of sample and event selection options are:

EDF2ASC -ns	no samples, just events
EDF2ASC -neye	just samples, messages, button events, and data block events
EDF2ASC -ne	nothing but sample data
EDF2ASC -ns -neye	file structure outline: messages, buttons, data block events

Add to these options any sample-data selectors, and eye (-l, -r) data selectors required.

4.8.2.4 Special Data Options

The formatting of numerical data as text requires the use of a special symbol or value to indicate missing or undefined data. For example, eye position data is missing during a blink, as no pupil is present. In some EDF files, required velocity or resolution data is missing.

By default, such missing data is replaced with a dot ".". Any string or value can be used to replace the missing data. This value is specified with the "-miss" option, which is followed by the value to be used. One possibility is to use a very small value, such as "1e-8".

Resolution data is not available in some EDF files, or for raw pupil-position data. A default resolution value can be set using the "-defres" option, which is followed by the x and y resolution values. A fixed resolution value for gaze data and pupil-position data may be forced by using the "-setres" option in a similar manner. Forcing use of a preset resolution may allow recovery of data where system setup was incorrect, or to regularize velocity computations. Suggested values of forced resolution are 200 to 400 for raw pupil-position data, and 22.0 for gaze-position data. The latter assumes standard system setup (subject's eyes distant from the display by twice its width) and 640 by 480 pixel display resolution.

4.8.2.5 Summary of Options

-l or -nr	outputs left-eye data only if binocular data file
-r or -nl	outputs right-eye data only if binocular data file
-sp	outputs sample raw pupil position if present
-sh	outputs sample HREF angle data if present
-sg	outputs sample GAZE data if present (default)
-res	outputs resolution data if present
-vel	outputs velocity data in samples if possible
-s or -ne	outputs sample data only
-e or -ns	outputs event data only
-nse	blocks output of start events
-nmsg	blocks message event output
-neye	outputs only non-eye events (for sample-only files)
-miss <string>	replaces missing data in ASC file with <string>
-setres <xr> <yr>	uses a fixed <xr>,<yr> resolution always
-defres <xr> <yr>	uses a default <xr>,<yr> resolution if none in file

4.9 The ASC File Format

The ASC file format is defined by the type of data lines that appear in it, the format of these lines, and the order in which these lines occur. Data lines consist of several types:

- Blank or comment lines, which are ignored. The first non-blank character on a comment line is one of "#", "/" or ";".
- File preamble or file-description lines. These begin with "***". Usually these lines are ignored when processing the ASC file.

- Sample data lines. Each line begins with a number, representing the time of the sample.
- Event and data-description lines. Each line begins with a keyword, identifying the type of data in the rest of the line.

4.9.1 ASC File Structure

For sample-only ASC files, file structure is very simple. These files are produced using the "-s" or "-ne" options of EDF2ASC, and only sample data lines are present. There is no data on what type of eye-position data or which eye produced the data. Recording blocks are separated by samples lines consisting of missing-value data (dots or the string specified with the "-miss" option). Gaps in the sequence of sample timestamps may also be used to determine sample block divisions.

For ASC files containing events (and optionally samples), the order of lines is carefully structured. The order of items in an ASC file is similar to that of a sorted EDF file. The file begins with a copy of the EDF file's preamble, with each line preceded by "***". The preamble reports the file version, date created, and any description from the application. Usually the preamble is ignored during analysis.

The sequence of events and samples in the ASC file follows strict rules. These are:

- START events mark the beginning of each recording block, and END events mark the end of each block. The START events also specifies which eye(s) data is present, and if samples, events, or both are present.
- Data-specification lines follow each START event. These specify the type of data in samples and events in the block, and allow flexible data processing without prescanning the file.
- All eye-movement samples and events occur between the START event and the matching END event.
- All events and samples appear in temporal order. That is, the timestamps of samples, end-time timestamps of eye-movement end events, and start-time timestamps of all other events will be the same or greater than any preceding data.
- Eye-data samples are nested between eye-movement start and end event. For example, the first sample in a fixation will follow the SFIX event for that fixation, and the EFIX event for a fixation will follow the last sample in the fixation. This allows on-the-fly classification of samples as the data file is read.

Before writing an analysis program to process an ASC file, it is helpful to convert a small EDF file containing the data of interest, and examine it with a word processor or print it out.

4.9.2 Sample Line Format

Sample lines contain time, position, and pupil size data. Optionally, velocity and resolution data may be included. Several possible sample line formats are possible. These are listed below.

Essentially, each sample line begins with a timestamp. This is followed by X and Y position pairs and pupil size data for each eye, and optionally by X and Y velocity pairs for each eye, and resolution X and Y values. For binocular data, the resolution is the average of the left and right eye values. Missing data values are represented by a dot ("."), or the text specified by the "-miss" option to EDF2ASC.

SAMPLE LINE FORMATS

- Monocular:
 <time> <xp> <yp> <ps>
- Monocular, with velocity
 <time> <xp> <yp> <ps> <xv> <yv>
- Monocular, with resolution
 <time> <xp> <yp> <ps> <xr> <yr>
- Monocular, with velocity and resolution
 <time> <xp> <yp> <ps> <xv> <yv> <xr> <yr>
- Binocular
 <time> <xpl> <ypl> <psl> <xpr> <ypr> <psr>
- Binocular, with velocity
 <time> <xpl> <ypl> <psl> <xpr> <ypr> <psr> <xvl> <yvl> <xvr> <yvr>
- Binocular, with and resolution
 <time> <xpl> <ypl> <psl> <xpr> <ypr> <psr> <xr> <yr>
- Binocular, with velocity and resolution
 <time> <xpl> <ypl> <psl> <xpr> <ypr> <psr> <xvl> <yvl> <xvr> <yvr> <xr> <yr>

DATA NOTATIONS

<time>	timestamp in milliseconds
<xp>, <yp>	monocular X and Y position data
<xpl>, <ypl>	left-eye X and Y position data
<xpr>, <ypr>	right-eye X and Y position data
<ps>	monocular pupil size (area or diameter)
<psl>	left pupil size (area or diameter)
<psr>	right pupil size (area or diameter)
<xv>, <yv>	instantaneous velocity (degrees/sec)
<xvl>, <yvl>	left-eye instantaneous velocity (degrees/sec)
<xvr>, <yvr>	right-eye instantaneous velocity (degrees/sec)
<xr>, <yr>	X and Y resolution (position units/degree)

4.9.2.1 Samples recorded in Corneal Reflection Mode in EyeLink II

If the data file being processed was recorded using corneal reflection mode, each sample line has an added 3 (monocular) or 5 (binocular) character fields after all other fields (including resolution and velocity if enabled). These fields represent warning messages for that sample relating to the corneal reflection processing.

- MONOCULAR Corneal Reflection (CR) Samples

- "..." if no warning for sample
- first character is "I" if sample was interpolated
- second character is "C" if CR missing
- third character is "R" if CR recovery in progress

- BINOCULAR Corneal Reflection (CR) Samples

- "....." if no warning for sample
- first character is "I" if sample was interpolated
- second character is "C" if LEFT CR missing
- third character is "R" if LEFT CR recovery in progress
- fourth character is "C" if RIGHT CR missing
- fifth character is "R" if RIGHT CR recovery in progress

4.9.3 Event Line Formats

Each type of event has its own line format. These use some of the data items listed below. Each line begins with a keyword (always in uppercase) and items are separated by one or more tabs or spaces.

DATA NOTATIONS

<eye>	which eye caused event ("L" or "R")
<time>	timestamp in milliseconds
<stime>	timestamp of first sample in milliseconds
<etime>	timestamp of last sample in milliseconds
<dur>	duration in milliseconds
<axp>, <ayp>	average X and Y position
<sxp>, <sy>	start X and Y position data
<exp>, <ey>	end X and Y position data
<aps>	average pupil size (area or diameter)
<av>, <pv>	average, peak velocity (degrees/sec)
<ampl>	saccadic amplitude (degrees)
<xvr>, <yvr>	right-eye instantaneous velocity (degrees/sec)
<xr>, <yr>	X and Y resolution (position units/degree)

4.9.3.1 Messages

- MSG <time> <message>

A message line contains the text of a time stamped message. This will have been sent to the EyeLink II tracker by an application, and contains data for analysis or timestamps important events such as display changes or subject responses. The <message> text fills the entire line after the timestamp and any blank space following it.

4.9.3.2 Buttons

- BUTTON <time > <button #> <state>

Button lines report a change in state of tracker buttons 1 through 8. The <button #> reports which button has changed state. The <state> value will be 1 if the button has been pressed, 0 if it has been released. Tracker buttons may be created to monitor any digital input port bit, and may be created by link commands or in the tracker configuration file BUTTONS.INI.

4.9.3.3 Block Start & End

- START <time> <eyes> <types>
- END <time> <types> RES <xres> <yres>

START lines mark the beginning of a block of recorded samples, events, or both. The start time is followed by a list of keywords which specify the eyes recorded from, and the types of data lines in the bloc. The eyes recorded from are specified by "LEFT" for left-eye monocular, "RIGHT" for right-eye monocular, and both "LEFT" and "RIGHT" for binocular. The types of data lines included are specified by "SAMPLES" for samples only, "EVENTS" for events only, and both "SAMPLES" and "EVENTS" for both.

END lines mark the end of a block of data. The <types> are specified, as it is possible to turn recording of samples and events on and off independently. However, this is not suggested, and for most applications the <types> in the END line can be ignored. The two values following the "RES" keyword are the average resolution for the block: if samples are present, it is computed from samples, else it summarizes any resolution data in the events. Note that resolution data may be missing: this is represented by a dot (".") instead of a number for the resolution.

4.9.3.4 Fixations

- SFIX <eye> <stime>
- EFIX <eye> <stime> <etime> <dur> <axp> <ayp> <aps>
- EFIX <eye> <stime> <etime> <dur> <axp> <ayp> <aps> <xr> <yr>

The start of fixations are reported with a SFIX line, which can be eliminated with the EDF2ASC "-nse" option. The <eye> is "L" or "R", indicating the eye's data that produced the event.

The end of and summary data on the fixation is reported with the EFIX line. This reports the time of the first and last sample in the fixation, and computes the duration of the fixation in milliseconds. The average X and Y eye position (the type of position data is determined when the event was generated) and the average pupil size (area or diameter) are reported. Optionally, the eye-position angular resolution (in units per visual degree) are given as well.

All samples that are within the fixation will be listed between the SFIX and EFIX event for each eye, simplifying data analysis.

4.9.4 Data-Specification Lines

Immediately following a START line, several lines of data specifications may be present. These lines contain more extensive data than the START line about what data can be expected in the START...END block. These are most easily processed by creating a set of flags for each possible data option (left-eye events, right-eye samples, sample velocity, etc.), clearing these when the START line is encountered, and setting the appropriate flags when keywords ("LEFT", "VEL", etc.) are encountered in a data specification line.

- PRESCALER <prescaler>

If gaze-position data or gaze-position resolution are used for saccades and events are used, they must be divided by this value. For EDF2ASC, the prescaler is always 1. Programs that write integer data may use a larger prescaler (usually 10) to add precision to the data.

- VPRESALER <prescaler>

If velocity data is present, it must be divided by this value. For EDF2ASC, the prescaler is always 1. Programs that write integer data may use a larger prescaler (usually 10) to add precision to the data.

- EVENTS <data type> <eyes> <data options>

This specifies what types of data is present in event lines, as a sequence of keywords. The <data type> is one of "GAZE", "HREF" or "PUPIL". The eyes recorded will be one or two words, "LEFT", "RIGHT", or both. The <data option> keywords currently supported are:

- "RES" for resolution data (both may be present).
- "RATE" for the sample rate (250.00 or 500.00)
- "TRACKING" for the tracking mode (P = Pupil, CR = Corneal Reflection)
- "FILTER" for the filter level used (0=off, 1=standard, 2=extra)

- SAMPLES <data type> <eyes> <data options>

This specifies what types of data is present in sample lines, as a sequence of keywords. The <data type> is one of "GAZE", "HREF" or "PUPIL". The eyes recorded will be one or two words, "LEFT", "RIGHT", or both. The <data option> keywords currently supported are:

- "VEL" for instantaneous velocity data
- "RES" for resolution data (both may be present).
- "RATE" for the sample rate (250.00 or 500.00)
- "TRACKING" for the tracking mode (P = Pupil, CR = Corneal Reflection)
- "FILTER" for the filter level used (0=off, 1=standard, 2=extra)

4.10 Processing ASC Files

An ASC file is a simple text file, and thus can be accessed by almost any programming language. The usual way to process the file is to read each line into a text buffer (at least 250 characters in size), and to scan the line as a series of tokens (non-space character groups). The first token in each line identifies what the line is:

First character in first token	Line type
<no token>	Blank line--skip
# or ; or /	Comment line--skip
*	Preamble line--skip
Digit (0..9)	Sample line
Letter (A..Z)	Event or Specification line

Once the line is identified, it may be processed. Some lines may simply be skipped, and the next line read immediately. For sample lines, the tokens in the line can be read and converted into numerical values. The token "." represents a missing value, and may require special processing. For lines where the first token begins with a letter, processing depends on what the first token is. The tokens after the first are read and desired data from the line are extracted from them. Lines with unrecognized first tokens or with unwanted information can simply be skipped.

Processing of events and samples will depend on what type of analysis is to be performed. For many cognitive eye movement analyses, MSG line text specifying experimental conditions, EFIX event data, and BUTTON event times from each block are used to create data files for statistical analysis. For neurological research, samples between SFIX and EFIX events can be processed to determine smooth-pursuit accuracy and gain. In some cases, an entire block of samples may need to be read and stored in data arrays for more complex processing. For all of these, the organization and contents of the ASC files have been designed to simplify the programmer's task.

EDF2ASC can compute velocity, which saves a lot of effort for the programmer writing smooth pursuit and saccadic analysis software. If acceleration is needed as well, subtract adjacent sample's velocities and multiply by the number of samples per second (250 or 500)

4.11 An ASC File Processing Program

See the ASC directory in the Developer's kit. The files READ_ASC.C and READ_ASC.H implement an ASC file parser. The ANA.C program uses this to process trials from DEMO.EXE, and can be used as a template for creating your own analyzers. Any program that uses the standard messages used by DEMO.EXE will work with this.

5. Troubleshooting

Here are some common and not so common problems that can be encountered with the EyeLink II system. If the suggestions provided here do not solve the issue, please contact a SR Research representative.

Problem: Eye Camera Images are blank or blue

- Ensure headband cable is connected to the EyeLink II PCI card in Host PC. Be sure Host PC is OFF before connecting cable.
- Ensure the lens caps have been removed from the eye cameras.
- Auto Threshold the camera image to set the threshold properly.

Problem: Head Camera Image is not displaying Markers

- Ensure marker cable is connected to EyeLink II PCI card in Host PC. Be sure Host PC is OFF before connecting cable.
- Auto Threshold the camera image to set the threshold properly.

Problem: Receive Connection Error when starting Experiment on Display PC

- Ensure the Ethernet cable is connected from the Display PC to the EyeLink II PCI card in Host PC.
- Restart the EyeLink II Host Application on the Host PC

Problem: LED Warning on Host PC startup

If a warning message concerning LED currents or safety circuits appears at startup, or if the EyeLink software terminates with such a message, there may be a problem with the headband, headband cable, or EyeLink card. If such an error occurs:

1. Make a copy of the "EYE.LOG" file.
2. Turn off the computer for at least 10 minutes to allow the protection devices on the EyeLink card to reset.
3. Restart the EyeLink II system.

If the error reoccurs after restarting the software, contact SR Research customer support with a description of the problem and a copy of the EYE.LOG file from each session where the error occurred.

Problem: Host PC Warning Message or Image Loss

If an error occurs that produces a warning message or causes a loss of images in one or more cameras, contact SR Research for troubleshooting instructions, and be prepared to e-mail the copies of the EYE.LOG files. Do not operate the computer with the EyeLink card installed unless directed to by SR Research. If

SR Research determines that a hardware problem is likely, you will be requested to return the headband, EyeLink card and possibly the marker set to SR Research for testing and repair. This is because there are no user-serviceable parts on the EyeLink II card or on the headband. Be sure to follow the packing instructions you received with the system when repackaging the EyeLink II into its shipping case. Under normal circumstances SR Research will send a replacement system to you.

6. System Care

6.1 Maintenance

The EyeLink II system should require little maintenance under normal use. The plastic parts of the headband and the leather padding may be wiped with a damp cloth if cleaning is required. Metal parts of the headband and the lens of the head camera may be wiped gently with a clean, dry, soft cloth. The lenses of the eye cameras are recessed to prevent finger contact and should only rarely require dusting with a lens brush.

The camera support arms may occasionally require cleaning to remove dust and oils and restore smooth motion. **DO NOT LUBRICATE THE ARMS OR UPPER CLAMPS**—cleaning should be sufficient to restore smooth operation.. To clean these, loosen the upper clamps and allow the arms to slide down until 5mm of the arm remains above the clamp. Tighten the clamp and then use a soft, dry, clean cloth or facial tissue to gently rub the vertical part of the arms. Use light pressure and up-and-down strokes only. After cleaning, restore the arms to their fully raised position.

If the headband cable feels stiff or begins to form loops, it has become twisted. This twist must be removed to restore the flexibility of the cable and to avoid shortening its life. The easiest way to untwist the cable is to hold the headband by its top clamp and rotate it through one or more turns in the direction that will undo the twist. If the twist is severe, it may be necessary to disconnect the headband from the EyeLink card, untwist the cable, and reconnect the headband. Once untwisted, the cable may also be relaxed by holding the cable 20 cm from the headband with the wires inside the sheath parallel, then gently shaking the cable. Move down the cable 30cm at a time for at least 2 metres. Next, gently slide your fingers along the sheath from 2 metres down the cable towards the headband, to ensure that the sheath is loose near the headband.

6.2 Storage and Transportation

Between uses, it is recommended that the EyeLink II headband be placed on a glass or foam dummy head. If the EyeLink II system is not going to be used for an extended period, you may wish to disconnect the headband and marker cables from the computer and pack these in the shipping case, as detailed below. The EyeLink II card may be left inside the Host PC, although it may be removed if this computer is going to be used for another purpose, to prevent theft or loss.

For long-term storage, shipping, or transportation, it is recommended that the EyeLink II headband and marker cable be stored in the shipping case that you

originally received the system in. Printed instructions are attached under the foam insert in the lid of the case, and are duplicated here.

Store the shipping case above freezing and below 40°C, and avoid high-humidity conditions which might cause water to condense within the headband and damage the optics. Be sure to follow the unpacking and installation instructions when returning the packaged unit to operation.

To pack the headband:

1. Tighten the height adjustment and rear clamps as far as possible.
2. Loosen the upper clamps and slide the camera arms up as far as possible.
3. Tilt the arms up so the cameras are nearly parallel to the headband frame, and point the cameras down.
4. To prevent scratching of the arms and head camera, place the cardboard spacers between the arms and the head camera, then fold the arms up against the head camera.
5. Place the camera lens caps on the eye cameras.
6. Place the supplied bubble wrap around the eye cameras and between the eye cameras and the head camera.
7. Place the headband into the foam cutout, with the cable through the back of the cutout.
8. Place the foam bag over the connector end of the headband cable.
9. Feed the headband cable into the foam cutout, making a figure-eight pattern to avoid twisting the cable.
10. Use the wire tie around the middle of the cable, or place the supplied plastic bag over the cable.
11. The marker cable should be removed from the Velcro patches on the monitor, and the foam bag placed over the markers.
12. Bundle the cable into the foam cutout on top of the headband cable to ensure it will fit, then remove it and place it into the plastic bag.
13. Place the bagged marker cable back into the cutout over the headband cable.

If the EyeLink II card is also to be packaged, remove it from the computer and place it into its anti-static bag, then into its slot in the foam.

Close the shipping case, checking for excessive pressure that may indicate an obstruction. Ensure the latches are closed, then place the case inside its cardboard shipping box. This box may then be sealed and shipped without additional padding by courier.

7. Important Information

7.1 Safety

7.1.1 Electrical Isolation Safety



Type BF equipment: metal parts connected to chassis of computer may contact user. Compliance with 601-1 medical equipment standards requires use of a medical grade power supply.

The EyeLink II system has been certified to comply with medical electrical equipment standards (UL 2601-1, CSA C22.2 No.601.1 and IEC 60601-1). The electrical isolation required by these standards is more stringent than required for regular computer power supplies, therefore the EyeLink II host computer requires a medical-grade power supply to meet these standards. The Ethernet connection to the Display PC is electrically isolated, and the standard EyeLink configuration (the EyeLink Host PC and the Display PC connected by the Ethernet cable) is 601-1 compliant.

Even with the use of a medical-grade power supply, direct connection of other AC-powered devices to the EyeLink II Host PC may provide sources of leakage currents above those permitted by the 601-1 standards. For this reason, digital inputs or analog outputs from the Host PC and connected to another PC or to recording devices may affect the 601-1 certification. Therefore these connections should not be used unless medical-grade isolation is not required or isolation has been tested for the complete configuration.

7.1.2 Eye Illumination Safety

The EyeLink II system is compliant with the IEC-825 LED safety standard as a Class 1 LED device, and incorporates an active LED current monitoring system to ensure compliance even if hardware faults occur. This circuit also shuts off power to all illuminators and markers when the EyeLink II software is not running. The operation of this safety system is verified when the EyeLink II software starts, and LED currents are monitored continuously while the software runs.

7.2 Limited Hardware Warranty

SR Research Ltd.

5516 Main St., Osgoode, Ontario, Canada K0A 2W0

EyeLink II Product Hardware– Limited Warranty

SR Research Ltd. Warrants this product to be free from defects in material and workmanship and agrees to remedy any such defect for a period as stated below from the date of original installation.

EyeLink II High Speed Eye Tracker Headband and Cable– One (1) year parts and labor.

EyeLink II High Speed Eye Tracker PCI Card– One (1) year parts and labor.

EyeLink II High Speed Eye Tracker Marker Cables– One (1) year parts and labor.

LIMITATIONS AND EXCLUSIONS

This warranty does not apply to any product which has been improperly installed, subjected to usage for which the product was not designed, misused or abused, damaged during shipping, or which has been altered or repaired in any way that affects the reliability or detracts from the performance. Any replaced parts become the property of SR Research Ltd.

The computer system that the EyeLink II product components are integrated with are excluded from this warranty unless expressly agreed to be otherwise in writing by SR Research Ltd; contact the original computer manufacturer for service and support for the computer system itself.

This warranty is extended to the original end purchaser only. Proof of original date of installation is required for warranty service will be performed.

This warranty does not apply to the software component of the product.

THIS EXPRESS, LIMITED WARRANTY IS IN LIEU OF ALL OTHER WARRANTIES, EXPRESS OR IMPLIED, EXCLUDING ANY IMPLIED WARRANTIES OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE.

IN NO EVENT WILL SR RESEARCH LTD. BE LIABLE FOR ANY SPECIAL, INDIRECT, OR CONSEQUENTIAL DAMAGES.

In certain instances, some jurisdictions do not allow the exclusion or limitation of incidental or consequential damages, or the exclusion of implied warranties, so the above limitations and exclusions may not be applicable.

WARRANTY SERVICE

For product operation and information assistance, please visit <http://www.eyelinkinfo.com> and submit a support request or contact a SR Research Ltd. Support representative. **For product repairs**, please contact your sales representative for appropriate instructions.

7.3 Limited Software Warranty

SR Research Ltd warrants that the software disks and CD's are free from defects in materials and workmanship under normal use for one (1) year from the date you receive them. This warranty is limited to the original owner and is not transferable.

The entire liability of SR Research Ltd and its suppliers, and your exclusive remedy, shall be (a) replacement of any disk that does not meet this warranty which is sent with a return authorization number from SR Research Ltd. This limited warranty is void if any disk is damaged has resulted from accident, abuse, misapplication, or service or modification by someone other than SR Research Ltd. Any replacement disk is warranted for the remaining original warranty period or 30 days, whichever is longer.

SR Research Ltd does not warrant that the functions of the software will meet your requirements or that operation of the software will be uninterrupted or error free. You assume responsibility for selecting the software to achieve your intended results, and for the use and results obtained from the software. SR Research will fix reported software error in a best effort fashion and can not provide a guarantee of solution availability time.

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7.4 Copyrights / Trademarks

EyeLink is a registered trademark of SR Research Ltd.

All other company and / or product names are trademarks of their respective manufacturers.

Product design and specifications may change at any time without notice.

8. Appendix A: Analog and Digital Output Card

The EyeLink II eye tracking system supports analog output and digital inputs and outputs via a DT334 card. The analog card supplies up to 8 channels of 16-bit resolution analog output, and 16 bits each of digital input and output. The analog outputs may be used to output up to 6 channels of eye and gaze position data for use by non-link and legacy applications. Digital inputs may be defined as buttons, used for controlling the EyeLink tracker, or recorded to the EDF data file. The outputs may be controlled by out-port commands via the link, or used by the EyeLink tracker for data strobes and other functions. A digital only card (the DT335) is also available.

This appendix describes how to configure and use the EyeLink II analog and digital outputs. While some ideas for input and control of the tracker will be introduced, applications are not limited to those introduced here. In addition, other digital input and output ports may be used, including the game ports and the printer port of the EyeLink II host computer.

8.1 Analog Data Quality

The EyeLink II analog output system is intended for use with commercial data-collection systems such as LabView, or for backwards compatibility with existing eye-tracking software and systems. However, analog data transfer may significantly degrade data quality compared to recording to file or digital transfer via the link. Typically, at least 1 or 2 bits of noise are added by the analog output, cabling, and re-digitization of analog signal transfer. The typical EyeLink noise level is 0.01 degree RMS: analog data transfer can increase the noise level by a factor of 2 to 20.

The EyeLink II system offers integrated data recording to file, and digital data transfer through the Ethernet link, which has latency comparable to the analog link and does not suffer from the time base, resolution, and noise degradation inherent in analog systems. SR Research Ltd is committed to improving access to the Ethernet link data transfer methods, and supplies an analog output option for backwards compatibility with existing experimental systems and as requested by users, but does not encourage its use in new systems.

8.2 Setting up the EyeLink II Analog Card

8.2.1 Installing Analog Output Hardware

The EyeLink II card must be installed before the analog card can be installed.

To install the analog output card, open the EyeLink II Host PC, install the card into an empty PCI slot, and secure the rear bracket of the card with the bracket screw or card clamp (depending on your computer model). The EyeLink II tracker software will automatically find and use the analog card.

8.2.2 Connections to Analog Card

The analog card is supplied with a connection cable and screw terminal connection board. Analog outputs and digital inputs and outputs are available from this card (see the document included with the screw terminal board for which terminals correspond to the analog outputs, digital inputs and outputs, and ground or +5V). It is up to each user to determine how to connect and use the analog output connections for their applications. Connections to the analog outputs will depend on what these outputs are connected to—typically this is another computer with an analog input card.

8.2.3 Noise and Filtering

It is very important to make sure these connections are made in way that does not introduce noise into the data, so connections between the analog output terminals and the analog input terminals must be as short as possible. If the analog input device does not have filters, it may be helpful to add a conditioning filter to each analog connection. A 470 ohm resistor between the output and input, and a 0.1 microfarad capacitor from the input to ground, will filter out most noise sources while not affecting the analog signals (this is a 3.4 KHz low pass filter, which should settle to 1% in 220 microseconds).

8.3 Digital Inputs and Outputs

The digital ports are configured by the EyeLink software with A0-A7 and B0-B7 as inputs, and C0-C7 and D0-D7 as outputs. A digital-only card is available when analog output is not required.

Digital outputs may be set by the `write_ioport` command, which may be issued though the link or by a button or initialization file command. The port address for the C and D ports on the EyeLink analog output card are 4 and 5,

respectively. Digital outputs may also be reserved for EyeLink tracker functions, and writing to these bits has no effect. For example, when analog output is enabled, the data output D7 is used as a strobe output to indicate when new analog data is available.

The digital inputs may be used as buttons and as input port bits, which may be recorded in the EDF data file, or sent as samples via the Ethernet link. Button inputs may be connected to a digital output (such as a printer port) from a control computer, and assigned functions such as starting and stopping recording, or used as synchronizing marks in the data file. When used as a real button for participant response, the button is typically connected to ground, a 10 K ohm resistor should be connected from the input to one of the +5V terminals on the connection board. Buttons and input ports are defined in `buttons.ini`, with port addresses of 2 for port A, and 3 for port B.

Here is an example of defining a button on port A, and assigning port B as the input port:

```
create_button 8 2 0x01 1 ; button 8, input A0, 0 is active
input_data_ports 3 ;; digital inputs B0..B7 as input port
input_data_mask 0xFF ;; use all bits
```

8.3.1 Analog Data Output Assignments

The EyeLink II system outputs analog voltages on 3 to 6 channels, depending on the mode of operation (monocular or binocular) and the analog card configuration. The monocular analog output configuration (set by the Set Options menu screen) should be used in most cases, as it assigns the eye being actively tracked to the first 3 channels. When binocular mode is selected, left and right eye data is assigned to fixed channels. The analog channel assignments may also be limited to 4 channels (using the `analog_force_4channel` configuration variable in `analog.ini`). This allows operation with binocular data when few analog inputs are available, and when pupil size data is not required. The results of all combinations of configurations and monocular/binocular eye tracking modes are summarized in the table below, with X and Y representing horizontal and vertical position data, and P representing pupil size data.

Eye tracking mode	Analog output mapping	Channels available	DAC0	DAC1	DAC2	DAC3	DAC4	DAC5
left / right	Monocular	6	X	Y	P	--	--	--
Binocular	Monocular	6	left X	left Y	left P	right X	right Y	right P
Left	Binocular	6	left X	left Y	left P	--	--	--
Right	Binocular	6	--	--	--	right X	right Y	right P
Binocular	Binocular	6	left X	left Y	left P	right X	right Y	right P
left / right	Monocular	4	X	Y	P	--	--	--
Binocular	Monocular	4	left X	left Y	right X	right Y	--	--
Left	Binocular	4	left X	left Y	--	--	--	--
Right	Binocular	4	--	--	right X	right Y	--	--
Binocular	Binocular	4	left X	left Y	right X	right Y	--	--

Table 1: Analog channel data assignments

8.3.2 Analog Data Types and Ranges

Both gaze and HREF position data are available for analog output. These are selectable through the EyeLink II tracker's Set Options menu screen. Each of these is scaled to a voltage on the analog output as described below. Raw pupil (or pupil-CR) data is also available for applications that implement their own calibrations.

8.3.3 Scaling of Analog Position Data

Each of the types of position data is scaled to match the selected analog output voltage range. Several variables in analog.ini set what proportion of the expected data range for each type will be represented at the output, and what the total voltage range will be.

- Total analog voltage range is set by `analog_dac_range`, followed by the highest and lowest voltage required. The voltage range may be from -10 to +10 volts, with other typical ranges being -5 to +5, or 0 to +10 volts.
- The fraction of the total data range to be covered is set by the `analog_x_range` and `analog_y_range` variables. These are followed by the data type, and the minimum and maximum range fraction. For example, 0 to 1.0 would cover the full range of the data, 0.1 to 0.9 would cover the central 80% of the data, and -0.2 to 1.2 would add a 20% margin above and below the expected data range.
- For raw data, the default range is 0.1 to 0.9, because the pupil position will never reach the edges of the eye camera image. It is possible that the scaled and transformed pupil-CR data might exceed this range, but in general this

range will be similar to that of the camera image. Raw data should be assumed to be in arbitrary units.

For HREF data, the entire data range is assumed to be -30000 to +30000. This is about 127°. This should never be exceeded. The default range setting is therefore 0.0 to 1.0. The HREF data may be recovered from the voltage by the following formula:

$$\text{HREF} = (\text{voltage} - (\text{minvoltage} + \text{maxvoltage} / 2) * 60000 / (\text{maxvoltage} - \text{minvoltage}))$$

- For gaze position data, the data range is scaled to the display coordinates, which are 640 by 480 at startup, and may be changed via link commands. The data range setting is -0.2 to 1.2, allowing 20% extra range for fixations that map to outside the display. This extra data range allows for slippage or for identification of fixations outside the display. Scaling to recover gaze position data is more complex, as the numerical value is partially dependent on the display coordinates. The following formulas do the conversion in several stages, with R being the voltage range proportion, and S being the proportion of screen width or height.

$$R = (\text{voltage} - \text{minvoltage}) / (\text{maxvoltage} - \text{minvoltage})$$

$$S = R * (\text{maxrange} - \text{minrange}) + \text{minrange}$$

$$X_{\text{gaze}} = S * (\text{screenright} - \text{screenleft} + 1) + \text{screenleft}$$

$$Y_{\text{gaze}} = S * (\text{screenbottom} - \text{screeentop} + 1) + \text{screeentop}$$

8.4 Pupil Size Data

For pupil size, either pupil area or pupil diameter may be monitored. These are very high-resolution measurements, with resolution as small as 5 microns (0.005 mm). Pupil size measurements are affected by eye position, due to the optics of the eye and cameras, and should be considered to be measured in arbitrary units, with a pupil size of zero being represented by the lowest analog voltage.

8.5 Time base and Data Strobe

The EyeLink II eye tracker samples eye position every 2 or 4 msec and outputs analog data at 250 or 500 Hz. This combination of fast sampling rate and non-continuous output differs from most eye-tracking systems with analog outputs, which either output continuous analog data (such as limbus-tracking systems)

or output samples at a lower rate, such as 50/60 Hz video-based tracking systems. This causes the EyeLink II analog output to rapidly step between data values, which means that sampling at fixed intervals makes it likely that samples might be missed, sampled twice, or the transition between samples might be recorded instead. Since the EyeLink II tracker and most data-acquisition systems rely on interrupt-driven software sampling and output, it is possible that time base jitter could result in missed samples, or repeated recording of a single eye-position sample. This would appear as a "step" artifact in rapidly-changing eye-position data, such as saccades or pursuit.

8.5.1 Strobe Data Input

The best time base method is to use the EyeLink II analog output strobe, which is assigned to digital output D7 on the analog card connection board. This signal can be configured to be a short or long trigger pulse, which can be used to trigger hardware data acquisition on analog input devices equipped for this, or to trigger interrupt-driven acquisition. The characteristics of this strobe pulse may be set in the analog.ini file, with the strobe being active-high or active-low, and with duration between 5 and 2000 microseconds.

The onset of the strobe is also delayed from the time that analog outputs change, in order to allow outputs to settle to the new voltages. A delay of 400 microseconds is standard, allowing the use of signal-conditioning low pass filters as discussed earlier.

8.5.2 Over sampling and Toggle Strobe

Another possibility is to over sample the analog output, by recording the analog outputs at more than twice the EyeLink II sample rate. This will prevent missed samples, but will still result in steps in the data. Recording the digital strobe output (on an analog or digital input channel) in combination with the analog data allows the first data from each sample to be selected, by detecting the change in value of this output. By setting the duration of the strobe pulse to 0, the strobe output can be set to toggle between high (4 to 5 volts) and low (0 to 1 volt) for every sample, which produces the best signal. Over sampling can also be used without the strobe when the analog data is being used to a drive gaze-contingent display, as the time of each sample is unimportant and over sampling will minimize total data delay.