EyeLink **System Documentation**

NOTE: This document version has appendices etc. removes, and concentrates on installation, setup, and development issues.

Version note: Start of update for SIMLINK 1.1, 20 Feb.
Notes on threshold added
Simlink moved to own documnet, 9 Jan ‘97

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1. *EyeLink* System Overview

Your *EyeLink* system consists of the following components:

- *EyeLink* Operator PC
    - PC compatible computer with MS-DOS 6.2 & MS-Windows 3.11. and the following *EyeLink* specific components installed:
    - Hi-speed eye tracking hardware
    - Ethernet card
    - *EyeLink* eye tracking software
    - optional *EyeLink* analog and digital I/O card
    - File viewing and analysis tools

    During operation this PC performs real-time eye tracking at 250 samples per second, also computing true gaze position on the subject display. On-line detection analysis of eye-motion events such as saccades and fixations is also performed. This data can be stored in a data file on the operator PC, sent through the Ethernet link to the subject PC, or output as analog signals (if the analog/digital I/O card is installed). From this PC, the operator performs subject setup, monitors performance, and can control applications running on the subject PC.
- *EyeLink* Subject PC
    - PC compatible computer with MS-DOS 6.2, MS-Windows 3.11, and the following components installed:
    - Ethernet card
    - *EyeLink* communication drivers and applications
    - File viewing and analysis tools
    - Applications running on this PC provide subject displays for experiments, and calibration targets during eye-tracker calibrations. On-line eye and gaze position can be received from the *EyeLink* Operator PC via the Ethernet link. Sample applications, C source code, and instructions for creating experimental applications are provided in the SimLink development kit.
- *EyeLink* headband with 2 high-speed eye cameras and 1 high-speed head position compensation camera

- *EyeLink* headband cable for connecting the *EyeLink* headband to the *EyeLink* Operator PC
- IR display marker set. This is mounted on the *EyeLink* Subject PC monitor to sense subject's head position
- Ethernet connection cable for connecting the *EyeLink* Subject PC and the *EyeLink* Operator PC

2. *EyeLink* System Installation

The first section of this chapter gives suggestions for equipment setup. After reading this, if your EyeLink system has come pre-integrated with hardware and software packages installed, proceed to section 2.7 for cabling instructions.

2.1 Suggested Equipment Layout

The layout of the EyeLink equipment is important if subject setup is to be convenient, and lighting problems are to be avoided. Before setting up equipment, check the arrangement of the room to be used against these suggestions. These will aid in the production of good experimental data.

- Set up the operator and subject monitors and PCs on tables arranged in an 'L' shape, as in Figure 1. This configuration allows the experimenter to set up the headband and the subject's left eye camera, while having access to both computer keyboards and monitors.

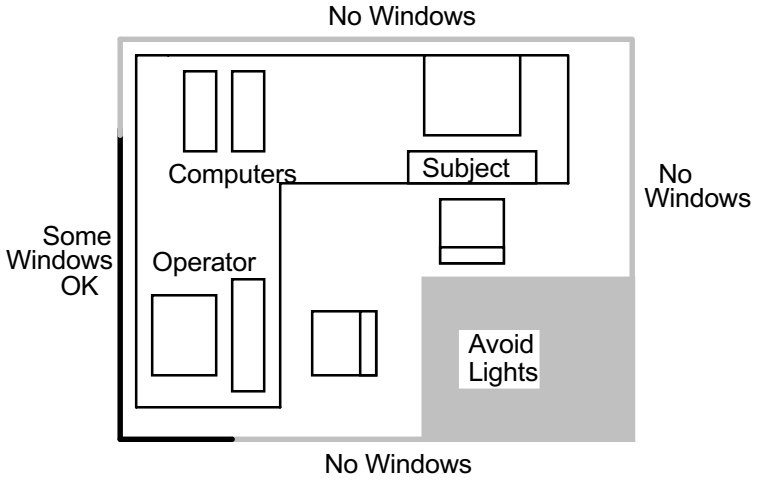

Figure 1: Suggested EyeLink System Layout

- Avoid windows or other bright light sources that could cause reflections on the operator and subject monitors. Windows or incandescent lights on the walls behind or near the subject monitor may interfere with the head-tracking camera. The grey walls in Figure 1 are locations where bright light sources will cause reflections.
- Supply sufficient light in the room. Dim rooms cause subject's pupils to dilate, which can cause setup problems with some subjects. The best way to light the room is with ceiling-mounted fluorescent lights, above and no more

than 2 meters behind the computer monitors. Painting the walls light colors or white will maximize ambient light as well.

- Avoid environmental distractions. Be sure the room can be kept quiet, that no posters or other items are on the wall seen by the subject, and so on. It is also a good idea to make sure the subject cannot see the operator monitor, without turning their head (discourage this).
- Supply a comfortable, stable chair for the subjects. It should not wobble or move when sat in, and the back should be firmly attached to the seat--springiness encourages some subjects to rock forwards and back. A chair with a concave back and seat also discourages shifting of the body, as does a high back. The top of the chair back should be just below the shoulders on an average subject. Finally, make sure subjects can enter and leave the chair easily, as the chair will be close to the table with the subject PC monitor.
- Set up the subject PC monitor and chair so that the subject's eyes will be at a distance from the monitor of about twice the width of the display area of the subject monitor. This distance gives a display area of 28° by 22°, and a resolution of about 22 pixels per visual degree at screen center. This standard distance is assumed in all EyeLink documentation: while the EyeLink system can measure and compensate for the eye-to-display distance, this is the ideal distance for both calibration accuracy and head-motion compensation.

2.2 Operator PC Hardware Installation

Install the *EyeLink* card, the I/O card (if included), the FASTEYE card, and the NE2000-compatible Ethernet card. These plug into the ISA bus slots.

Install the *EyeLink* headband adapter bracket into a free slot on the back of the operator PC. Be sure to chose a slot where the adapter PCB will not interfere with the cover or adjacent cards. The topmost slot in the PC (closest to the power supply on tower cases) usually works best. Plug the ribbon cable from the bracket into the connector on the side of the EyeLink card.

2.3 Operator PC Software Installation

The files on the installation disks have been compressed. If you do not have a copy of PKUNZIP on your computer, a copy is included on the tracker PC software disk. Copy it to the hard disk:

```
COPY  A:PKUNZIP.EXE  C:\
```

To create all files and directories, insert the "Tracker PC Software" disk into drive A:, then type:

```
MD  C:\EYELINK↵
CD  \EYELINK↵
PKUNZIP  -D  A:\EYELINK.ZIP↵
```

Add the following lines to your AUTOEXEC.BAT file:

```
PATH  C:\EYELINK\EXE;C:\EYELINK\EDF;%PATH%
C:\EYELINK\NET\NE2000X.COM  -t  0x60  5  0x320
```

The last line installs the driver for an NE2000-compatible Ethernet card at address 0x320, using interrupt 5. If you have to change these, also update the file `C:\EYELINK\EXE\EYENET.INI` file (as discussed below).

2.4 Subject PC Installation

Install the NE2000-compatible Ethernet card into an ISA bus slot. If your PC already has an Ethernet card connected to a network, you should still install this card, and connect the EyeLink PC to it. The EyeLink may send hundreds of packets per second in some data modes, which will cause problems with other network computers on the same cable. For TCP/IP systems, a bridge can serve to isolate the EyeLink cable from the rest of the network; for PCs, a second Ethernet card is the best solution. Be sure that the interrupts and addresses of the Ethernet cards do not interfere with each other.

Follow this procedure to install the files:

```
MD  C:\SIMLINK↵
CD  C:\SIMLINK↵
<insert Subject PC disk into a: drive>
PKUNZIP  -D  A:SIMLINK.ZIP↵
MD  DEV↵
CD  DEV↵
<insert EyeLink Development disk into a: drive>
PKUNZIP  -D  A:SIMDEV.ZIP↵
```

Add the following lines to your AUTOEXEC.BAT file:

```
PATH C:\SIMLINK\EXE;C:\SIMLINK\EDF;%PATH%
```

```
C:\SIMLINK\NET\NE2000.COM  0x60  5  0x320
C:\SIMLINK\EXE\SIMTSR.EXE
```

The second line installs the driver for an NE2000-compatible Ethernet card at address 0x320, using interrupt 5. The third line installs the *EyeLink* link TSR, which uses about 30K of memory. See the SIMTSR.EXE documentation for details. If you are low on system memory, you can install and remove the TSR as it is needed.

2.5 Changing I/O Addresses and Interrupts

The *EyeLink* hardware and software is pre-configured to use these addresses and interrupts:

EyeLink card:	0x340	interrupt 7
FASTEYE card:	0x278	no interrupt used
EyeLink I/O card:	0x380	no interrupt used
NE2000 Ethernet card:	0x320	interrupt 5

If you can use these addresses, no changes to configuration will be needed.

Otherwise, you'll have to change the address DIP switches and interrupt jumpers on the cards (follow directions printed on the cards), and edit the configuration files as described below. These files are found in C:\EYELINK\EXE on the operator PC, and in C:\SIMLINK\EXE on the subject PC.

If you need to change the *EyeLink* address or TIRQ interrupt jumpers (no VIRQ jumper is needed), you will need to edit the `HARDWARE.INI` file, updating the `hieye_base_address` and `timer_interrupt entries`.

If the NE2000 Ethernet card address is changed on either the operator or subject PC, you will need to update the following line that you added to your `AUTOEXEC.BAT` file on that machine:

```
C:\EYELINK\NET\NE2000X.COM  -t  0x60  5  0x320
```

or

```
C:\SIMLINK\NET\NE2000.COM  0x60  5  0x320
```

Change the '5' to the interrupt used, and the '0x320' to the address used. On the operator PC, you will also need to update the packet_driver entry in the `EYENET.INI` file.

If the FASTEYE card address jumpers need to be changed, no updates are needed as the software auto-configures for its address.

If the address of the I/O card is changed from 0x380, there are many changes needed to all of these configuration files on the operator PC:

```
C:\EYELINK\EXE\ANALOG.INI
C:\EYELINK\EXE\BUTTONS.INI
C:\EYELINK\EXE\IOCTRL.INI
```

It is best to use an editor to do a search-and-replace operation on the files. For example, to change the I/O card address to 0x3C0, do a search-and-replace from '0x38' to '0x3C'.

2.6 Headband and Marker Installation

For 17" VGA monitors, install the Velcro pads and markers in the position shown below. Plug the cable from the markers into the 9-pin connector on the back of the *EyeLink* card. Marker cables may be taped to the side of the monitor to decrease their visibility.

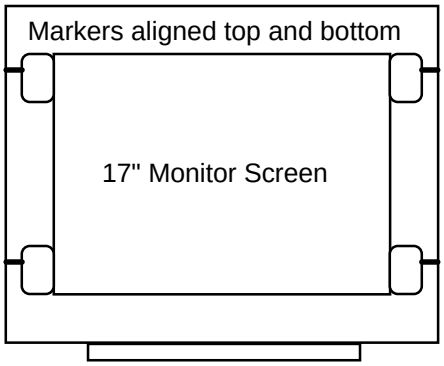

Figure 1: Marker set-up on EyeLink Subject Monitor

The final step is to update the details of your physical system, by adjusting the numbers in the `PHYSICAL.INI` file (located on the operator PC in the C:\EYELINK\EXE directory). The first step is to enter the calibration numbers from the back of the head camera into the PHYSICAL.INI file. Carefully tilt the head camera forwards, and write down the 'OX, 'OY', 'SX', and 'SY' values. Now update the file line beginning with `hcam_center` with the 'OX' and 'OY' values, and the line beginning with `hcam_scale` with the 'SX' and 'SY' values. Note: for current headbands, all these numbers should be negative: add a '-' to the number if it doesn't have one.

All the other EyeLink system parameters are pre-configured to work with a 17" VGA monitor, using 640 by 480 display resolution. For other monitor sizes or resolutions, some further editing of the PHYSICAL.INI configuration file may be required. See Section...

2.7 EyeLink System Cabling

For system set-up, please follow the wiring diagram below.

WARNING: Switch off the PCs before connecting or disconnecting any cables, especially the head band connection! Ensure that the headband cable is properly connected and connectors are properly secured to the** Operator PC **and the headband before use.

CAUTION: Ensure that the power supply setting on the back of the PC (near the power jack) matches your local supply voltage!

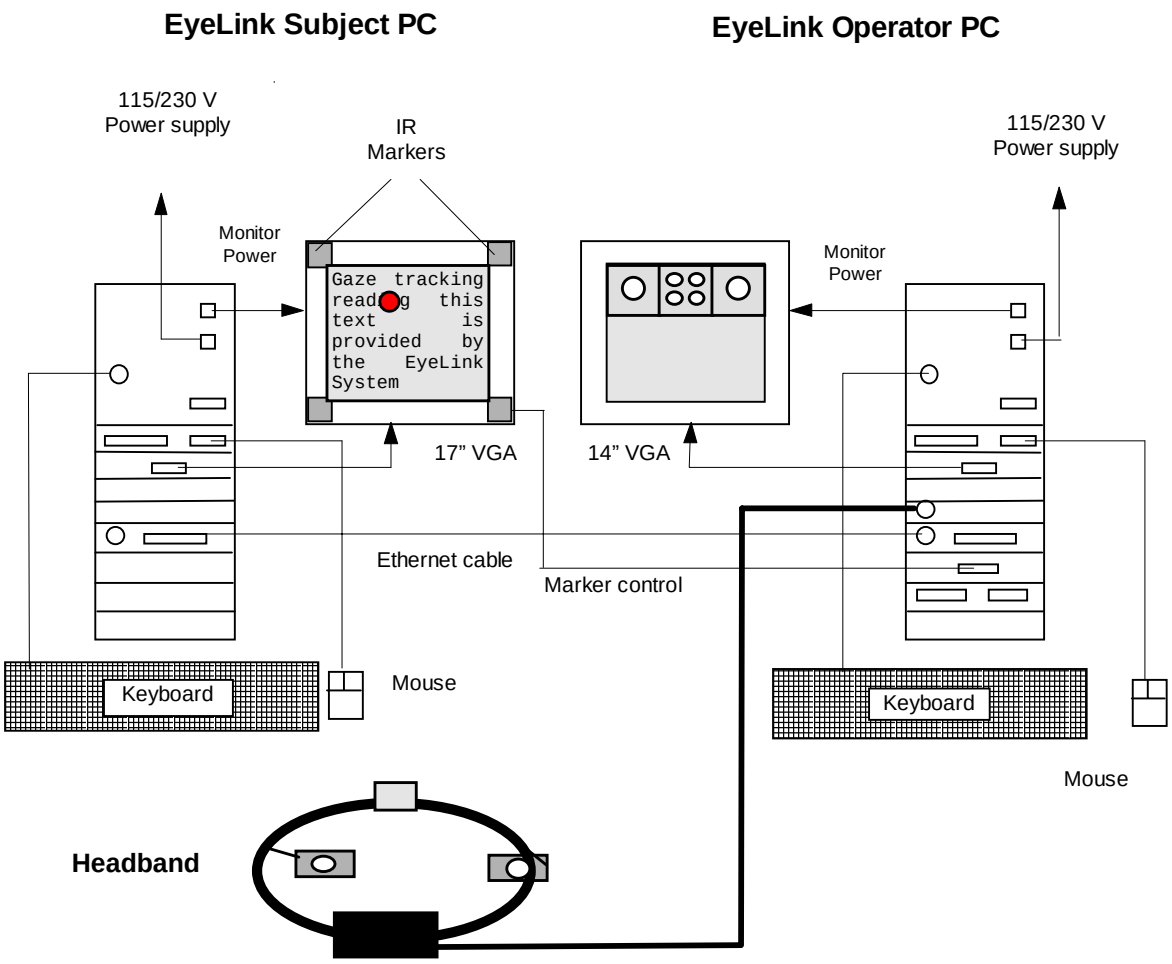

Figure 2: System set-up and cabling.

The cabling steps are:

Attach the keyboards, mouse, power cords, etc. to the PCs. This is probably already done, if the software was installed.

Connect the monitors. The 17" monitor with markers is attached to the subject PC, and the 14" monitor to the operator PC. Some monitors have power cords that will plug into the switched socket on the PC power supply.

Plug the cable from the monitor markers into the 9-pin connector on the back of the EyeLink card.

Attach the ends of the Ethernet cable to the BNC connectors on the Ethernet cards in the two PCs. The cables must have a 'T' connector and terminator attached to each end, and cannot connect directly to the Ethernet cards.

Plug the EyeLink headmount's cable into the EyeLink adapter connector on the back of the PC. Some headband cables will snap into place, and can be removed by pulling on the knurled barrel of the connector. Others need to have the ring unscrewed, then pulled. Check this at installation, and always pull on the ring of the connector, never the cable.

2.8 Operator PC Tests

After all cables are connected to both PCs, switch on the operator and wait for the MS-DOS prompt to appear. During startup on both PCs, the Ethernet driver (NE2000X.EXE) will print status messages, with the last line similar to:

```
My Ethernet address is 00:00:21:51:59:26
```

If the address is 'FF:FF:FF:FF:FF:FF', the packet driver was not able to initialise the Ethernet card: check the address, interrupts, etc., and update the AUTOEXEC.BAT and EYENET.INI files. Reboot the PC to test the new configuration.

On the operator PC, type

```
CD \EYELINK\EXE ↵
EYELINK ↵
```

As the EyeLink software starts up, messages will report the hardware configuration. If Ethernet or other hardware problems are found, the software will print an error message and stop. Usually this is because the EyeLink card or the FastEye card is not properly installed, or the Ethernet card or driver is not properly configured. Check that all cards are inserted correctly, and that the jumper and switch settings match those in the HARDWARE.INI file in the C:\EYELINK\EXE directory. Finally, changing the address or interrupts of the cards may help if there is a hardware conflict in your PC: please contact technical assistance for suggestions.

If no problems were found, the EyeLink Off-line mode screen should now appear. Press the ENTER key to display the Setup menu screen. This has three camera views at the top and a menu of key functions. Select the center view with the left and right cursor keys, and press ENTER to see the head-camera image. If the tracker exits at this point, you do not have enough free memory on your PC: remove some TSRs or drivers from CONFIG.SYS and AUTOEXEC.BAT, reboot, and try again.

When the front of the headband is pointed at the monitor, you should be able to see the four monitor markers as large white spots. If these are not seen, check that any protective stickers have been removed from the front of the

head camera. Otherwise, press the key combination 'CTRL+ALT+Q' *immediately* to exit the EyeLink software, shut off power, and check the headband cable connections and marker connections. You can check the camera and markers separately by pointing the head camera at an open window or incandescent lamp as well. Power to the markers can be checked by disconnecting the headband and running the EyeLink software for 2 minutes: they should be slightly warm to the touch.

Press the right arrow key to select the right eye camera image, and move a finger about 4 cm in front of the right eye camera. You should see a white image of the finger. Don't worry if horizontal breaks appear in the image: this is normal for non-eye images and does not affect performance. There may be a cable or headband problem if the image is completely black. Press the right arrow key again to select the left eye camera, and repeat the test. If any or all of the camera views are totally black, press the key combination 'CTRL+ALT+Q' *immediately* to exit the EyeLink software, shut off power, and check the headband cable connections.

2.9 Subject PC Tests

With the operator PC running the EyeLink software, switch on the subject PC, and watch for the Ethernet driver startup message on the operator PC. The SimLink TSR will also print a startup message: check that it installed properly. If Ethernet card address changes are needed, you will only have to edit the AUTOEXEC.BAT file on the subject PC as the SimLink TSR is self-configuring.

On the subject PC, type

```
CD \SIMLINK\EXE ↵
TRACK ↵
```

If there is a problem, the software will terminate with an error message:

- *Cannot Initialize Link*: Check that the Ethernet card and driver are properly set up. Reboot the subject PC and check the Ethernet driver's startup message, as detailed for the operator PC.
- *Wrong TSR version installed*: Either the operator PC software or the subject PC software is out of date. Check the software versions and file dates on EYELINK.EXE and SIMTSR.EXE, and contact technical support. The version number is displayed at the bottom of the Off-line (startup) screen of EYELINK.EXE, and in the startup message for SIMTSR.EXE.

- *Connect timed out*: The tracker software is not responding, or there is no Ethernet connection. Check that the EyeLink tracker software is running on the operator PC. Even small Ethernet cable problems can cause connection failure. Be sure to check:
    - Is the Ethernet cable connected to both PCs?
    - Are both ends of the cable connected using the 'T' connectors and terminators? Connecting directly to the Ethernet cards will cause signal loss.

If the system is configured properly, the screen will blank and a message will appear at the top of the display indicating the EyeLink tracker mode. The operator PC's display will show a message "Packet Link Open" at the lower right corner.

Press 'ENTER' then 'D' on the operator PC's keyboard. The subject PC should now display a black target in the middle of its display. Press 'ESC' on the operator's keyboard, and the target should disappear. Press 'ENTER' again, and a camera image should appear on both displays.

This completes the link checks. You may now exit the EyeLink tracker software by pressing 'CTRL+ALT+Q' on the operator PC keyboard. The software on the subject PC should also terminate. If it doesn't, press 'ESC' once or twice on the subject PC keyboard.

3. An EyeLink Session: Setup Procedure

The following session will demonstrate and test the *EyeLink* 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 eye-tracking demonstration, and assumes there are no serious problems encountered. Therefore you should select a subject for the test that can sit still when required, and does not have eyeglasses. Once comfortable on 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 practised experimenter can set up a subject in less than a minute, including fitting, calibration, and validation.

If the *EyeLink* software is not yet running on the operator PC, start it by typing

```
CD \EYELINK\EXE ↵
EYELINK ↵
```

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

Now start a sample application on the subject PC by typing

```
CD \SIMLINK\EXE ↵
TRACK ↵
```

When TRACK starts, message will appear on the subject PC, and the tracker link status message (at the bottom right) should read "Packet Link Open". Once TRACK is running, all control is from the operator PC keyboard, and the application will respond the state of the *EyeLink* software by drawing appropriate graphics on the subject PC display. You can also control the tracker from the subject PC's keyboard, which allows the operator to work near the subject, or for self-setup.

3.1 The Setup Menu

The first step in an eye-tracking session is to set up the subject and eye tracker. Begin by pressing ↵ (ENTER) on the operator PC's keyboard to display the Setup menu screen. You will see three camera-image windows at the top of the display, with a key-function menu at the left side. Throughout the *EyeLink*

software, any red text in a grey box represents a key identifier. The available key-functions for each operating mode are always shown, either as a menu or at the top of the display.

In the Setup menu, you can select one of the three camera views by pressing the ⇐ and ⇒ keys. Pressing ↵ will start display of a greyscale image of the selected camera's view, on both the operator and subject displays. The ⇐ and ⇒ keys can also be used to change cameras from this display. Pressing ↵ again will return to the Setup menu.

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 subject PC display, you will have to be able to see the operator PC display as well.

The parts of the headband are labelled in Figure 3. The EyeLink system should be let run for 5 minutes after switching on power to the operator 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.

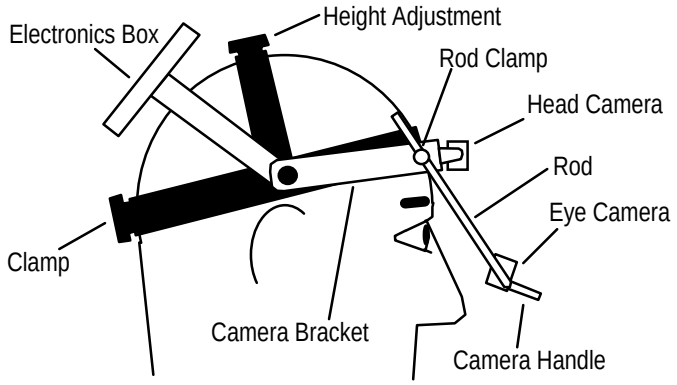

Figure 3: Parts of the EyeLink Headband

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 4 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. Holding the back in contact, 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.

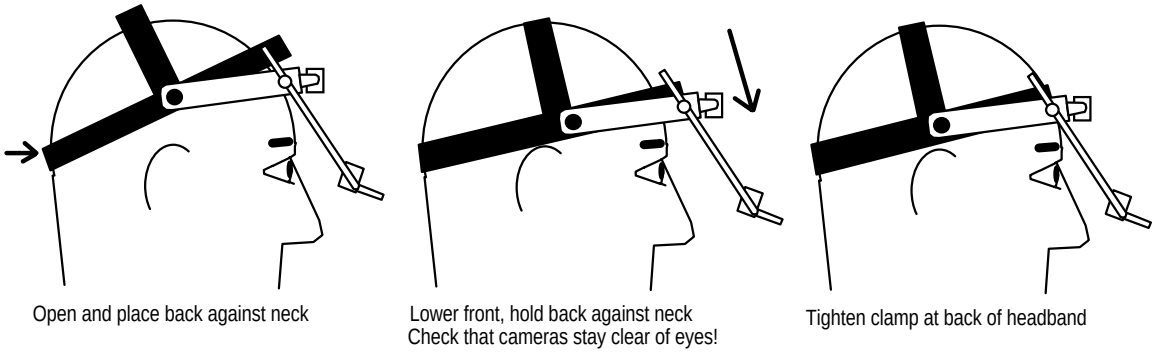

Figure 4: Applying and removing headband

Fit the headband so the front pad is in the center 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-position camera is centered above the subject's nose (Figure 2). 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 overtight.

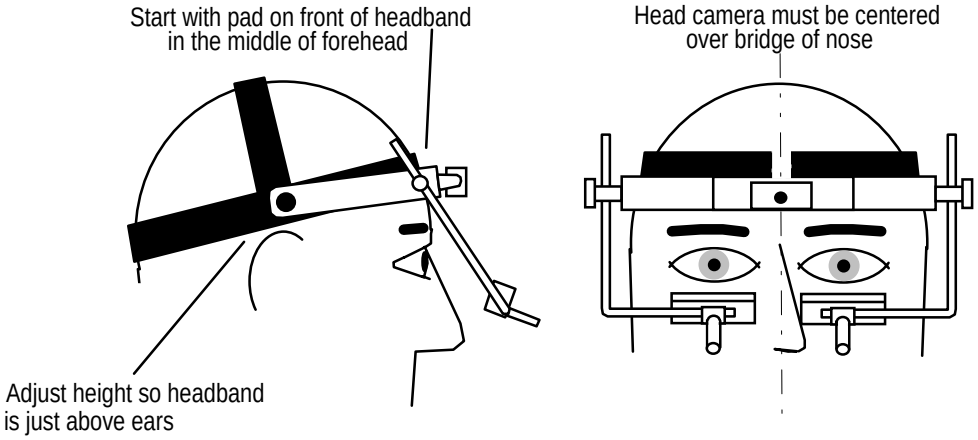

Figure 5: Initial Positioning of the Headband

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.

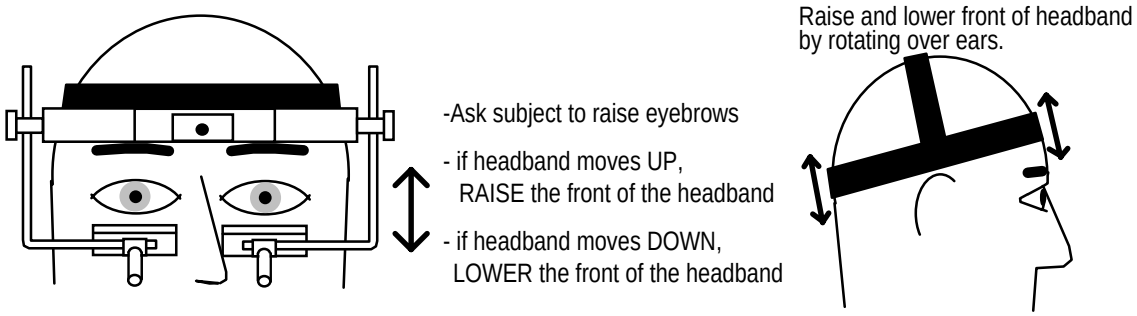

Figure 6: Adjusting point of contact with forehead.

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. 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.

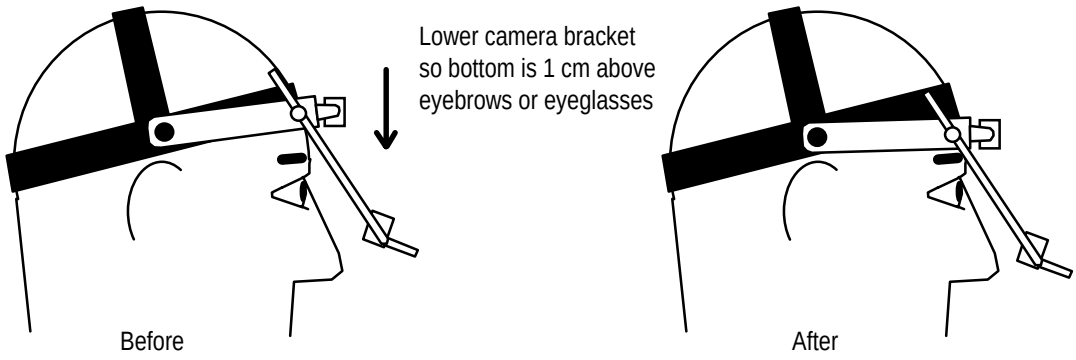

Figure 7: Positioning the camera bracket bar

The camera bracket on the front of the headband (the metal bar that holds the head camera) should now be pivoted downwards until the bar is just above the subject's eyebrows. If this is not done, head-motion compensation will be degraded.

3.3 Adjusting Eye Camera Position

From the Setup menu, select one of the eye cameras, and press ↵ (ENTER). You will probably not see the eye initially, until the cameras have been properly aimed. 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 7.

If the image becomes too dark or too light, wait one second while the auto-contrast adjusts itself. If green (thresholded) area in the display are interfering with setup, press 'T' to remove the threshold color overlay. In TRACK, you can use keys on either the subject or operator PC's to perform all operations while the eye image is displayed.

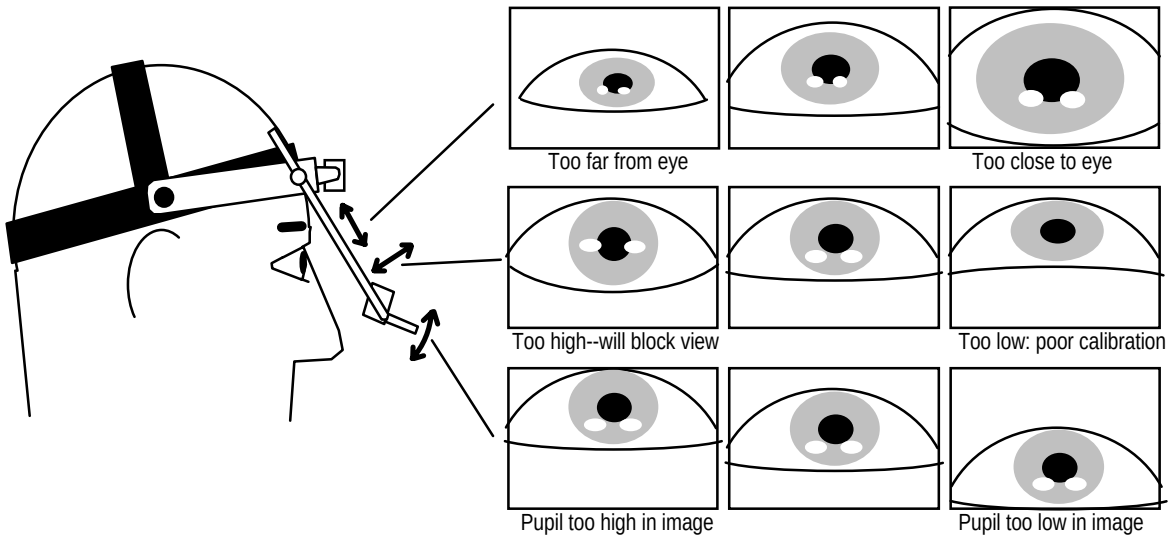

Figure 8: Size and Vertical Eye Camera Adjustments

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 7. 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.

Finally, the height of the eye camera below the eye may need to be adjusted, as in the middle row of Figure 7. 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 corneal reflections should be at the bottom edge of the pupil: lower the camera if they are too high.

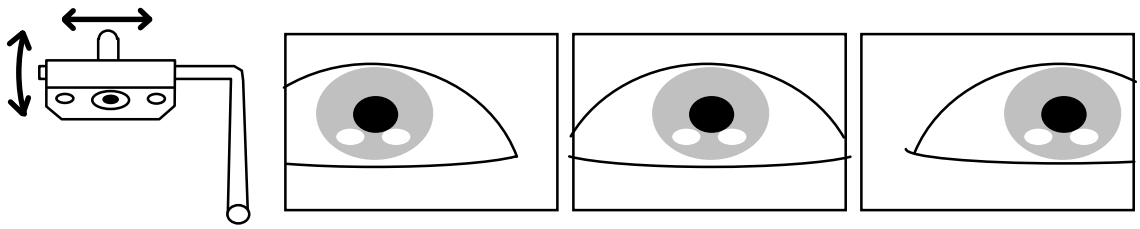

Figure 9: Horizontal Adjustments of Eye Camera

The pupil of the eye must now be centered 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 center the pupil. There are two camera clamp mechanisms in use: a spring clamp and a screw clamp. Squeeze the spring clamp handle to loosen and move the camera. For the round camera handle model, twist the camera handle to loosen the screw clamp, slide the camera, then retighten the handle.

The second method is to move the nose end of the camera rod towards and away from the face, twisting the rod though 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.

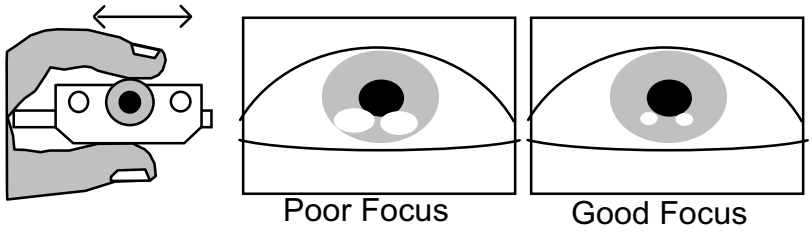

Figure 10: Focusing the Eye Camera

The eye camera should be focused by rotating the lensholder. The best focus will minimize the size of the two 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 lensholder 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.

3.4 Setting Pupil Threshold

The camera image of the eye should now be clear, with the pupil centered when the subject looks at the eye image on the subject computer's display. The pupil threshold may now be automatically set by pressing the 'A' key. When properly set, the pupil of the eye should be solidly green, with no other color in the image. If large areas are colored, the subject may have blinked: press 'A' 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 can be removed by special antireflection processing, enabled by pressing the 'R' key. Use this as little as possible, as it reduces the precision of head-position compensation and can increase pupil-tracking noise. Position the camera as close to the subject's glasses as possible to reduce noise. After setting the threshold, turn the anti-reflection off and then on again to be sure the pupil remains thresholded (see below).

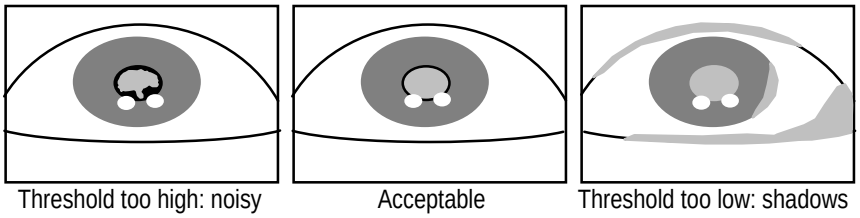

Figure 11: Symptoms of Poor Threshold

The pupil threshold should be checked by looking at the green areas in the image. Figure 10 shows the symptoms to look for. If the threshold is too low, the green 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 threshold with the ⇑ and ⇓ keys: a mnemonic is to think of the ⇑ key as increasing the green area, and the ⇓ key as decreasing the green area.

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 11. 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 ⇑ 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 10.

The pupil on the operator display 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 11), the box will disappear and the pupil will be lost.

The threshold can also be checked and adjusted in the Setup menu. Press ↵ (ENTER) to return to the Setup menu. The camera image display should now show a thresholded image of from all cameras, with the currently selected camera outlined in blue. You can use ⇑ and ⇓ to change the threshold on the selected camera, and ⇐ or ⇒ to change the selected image.

The 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.

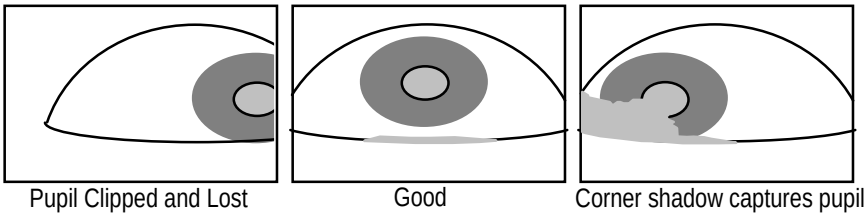

Figure 12: Corner Effects Seen with Head Rotation

Once you are satisfied with the eye-camera and pupil setup, you can select the other eye camera with the ⇐ or ⇒ keys, or return to the Setup menu by pressing ↵ (ENTER). It is recommended that both eyes be checked to determine the best tracking , even if only one is to be monitored.

3.5 Head Camera Setup

The thresholded images of all 3 cameras are displayed in the Setup menu display. After setup, the left and right eye images should clearly show the pupil, and the data display window at the bottom left should show both 'L' and 'R' position markers. The head camera image (top center) should show four large spots from the IR markers on the subject display. If any of these markers are near the top or bottom of the image, carefully rotate the head camera up or down to center them. Usually this will not be required, unless the head camera position has been disturbed. If the images of any of the four markers are missing or noisy, select the head camera and press ↵ to view its image.

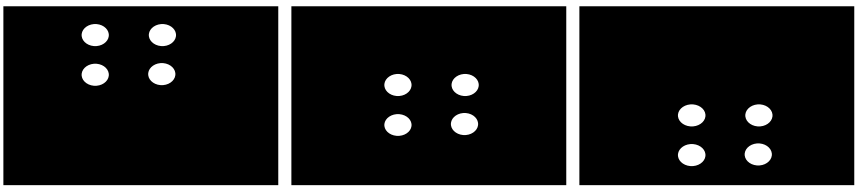

Figure 13: Head camera position adjustment

The head camera threshold is automatically set when any of the eye camera images is viewed. This thresholding almost always is correct, unless the markers are dim or the subject is very far from the display. To manually set the threshold, select the head camera view in Image mode, and press 'A' to set the camera threshold. 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.

3.6 Calibration

The preceding steps set up the EyeLink camera system to track the positions of the pupils of both eye and of the four IR markers. Almost all 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 subject display. We do this by performing a system calibration, displaying several targets for the subject to fixate. The pupil position for each target is recorded, and the set of target and pupil positions is used to compute gaze positions during recording.

Before calibrating, select the eye or eyes to be used. Pressing the 'E' key in the setup menu will select left eye, right eye, or both eyes (binocular) for calibration. For cases where binocular calibration is difficult, left and right eyes may be calibrated separately and used binocularly during recording. We recommend binocular calibration and recording, as this provides backup data if one eye's setup is poor. Data file (*.EDF) size will be doubled, however.

There are several possible calibration types available. Press 'S' from the Setup menu to display the Options menu, which allows selection of several options. 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

Press ↵ (ENTER) when done to return to the Setup menu.

Begin calibration by pressing 'C' from the Setup menu. A calibration target will appear on both the operator display and the subject display. The subject display is drawn by the TRACK.EXE application, in response to commands from the EyeLink system. The operator's display will also display the raw pupil position as a moving colored cross, and a thresholded eye camera image. A status bar at the bottom 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 becomes still when properly fixating the calibration target. Instructing the subject to carefully look at the black spot in the middle of the 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 eye has problems. The eye-movement condition is also visible at the right side of the status bar at the bottom of the operator's display.

Press the ↵ (ENTER) key or spacebar when the pupil appears stable to accept the first fixation. Some monitors blank for up to 1 second when video modes switch, so don't press the key until you're sure the subject has seen the target. 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 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 operator 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 Setup menu.

After the first fixation has been accepted, several more calibration targets are displayed in sequence, and fixations for collected each. The EyeLink 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 system detects these saccades and the fixation following, producing an automated sequencing system. 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 operator 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. 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.

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.

When the last calibration target has been presented, the calibration will be evaluated. Each eye's calibration is graded and displayed as :

GOOD (green background): No obvious problems found with the data

POOR: (grey background): Bad camera setup or one or more misfixations

FAILED: (red background): Could not use data, calibration must be repeated

The background color 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 ↵ key to accept the calibration results, or 'ESC' to restart the calibration. Pressing 'ESC' twice exits to the Setup menu.

3.7 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 may be immediately repeated.

In a validation, targets are presented on the subject display 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.

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 <0.005° 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, press the 'V' key in the Setup menu. The operator'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 appear 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. After the final fixation is collected, the average and worst error are displayed, 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 Setup menu, 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 setup problem. In this case, press 'ESC' to return to the Setup menu, and 'C' to re-calibrate.

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. Press ↵ to perform this correction, or 'ESC' to skip it.

3.8 Improving Calibration Quality

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

- 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 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.

3.9 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 'O' from the Setup menu 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 subject PC. When TRACK senses that the operator PC has entered Output mode, it sets up a recording session under its own control.

On the subject 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 operator 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 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 before recording begins.

TRACK displays the gaze position as a red cursor on the subject display. The cursor can be toggled on and off by the 'G' key on the subject PC keyboard. To implement this, TRACK requests that EyeLink send it 250 samples per second of gaze-position data through the link and SIMTSR link driver. This data is used to move the gaze cursor. (The version of TRACK supplied doesn't require the TSR to be loaded, as it contains it internally).

TRACK also sends commands to EyeLink to create a data file (`DATA.EDF`) on the operator PC's hard disk, which contains samples, fixations, and saccade data. When the TRACK exits, this file will be automatically transferred from the operator PC to the subject PC. `DATA.EDF` may be viewed with `EDFVIEW` (see Chapter 4 for information on this viewer) or processed with other EDF utilities.

Information on the EDF file format and tools can be found in the “EyeLink EDF Files” document.

If the optional analog and digital I/O card is installed, the gaze-position and other types of data are available as analog voltages. See Chapter 5 for details on the analog output system. This data is only output while EyeLink is in the Output mode.

Several forms of eye-position data can be sent to the analog output: gaze, HREF, pupil position, and pupil size data. These are covered in detail in the “EyeLink EDF Files” document. See Chapter 6 for analog-output information.

3.10 Exiting EyeLink

You can now exit EyeLink. Press the key combination ‘CTRL+ALT+Q’ from any point in the program to exit to DOS. On either PC, you can view the data recorded to TEST.EDF by typing

```
EDFVIEW TEST
```

This will display the data in the TEST.EDF file, including saccades, blinks, and messages. See Chapter 4 for more information on viewing data with the EDFVIEW utility.

3.11 EyeLink Setup Summary

It is suggested that you try the procedures in this section until you feel comfortable with EyeLink 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 on the operator PC.
- Start TRACK on the subject 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, press ↵ to view image.
- Aim the 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
- Return to Setup menu with ↵.
- 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 subject PC keyboard toggles gaze cursor on and off.
- Press 'CTRL+ALT+Q' to exit EyeLink

3.12 Experiment Practice

The TRACK.EXE program is the most flexible way to practice EyeLink setup, allowing almost any sequence of actions to be performed. In real experiments, the sequence of actions is much more defined. Usually the experiments 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 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.

The program DEMO.EXE implements a very simple four-trial experiment, and complete C source code is included in the developer's kit. To run DEMO, SIMTSR must be installed on the subject PC. Note before starting that may be difficult to stop before completion, as it has safeguards to prevent accidental termination and loss of data.

<... to be continued...>

4. EyeLink System Operation

4.1 ====REST OF SECTION UNDER CONSTRUCTION=======

4.2 Navigating Through EyeLink

The *EyeLink* eye tracker is a multipurpose, high resolution, real-time processing system. It is designed to be used in 3 different operation modes:

Analog/Standalone: In this mode, the eyetracker is an independent system, controlled by the operator by its keyboard. It is connected to a display-generating computer for the purpose of displaying calibration targets only. Calibration is only required to use head-position compensation. Data output is usually analog, and (until the next release, through the undocumented 'F9' menu) to files on the *EyeLink* eye tracker.

Link/Control: In this mode, the eyetracker is partially controlled by the display PC via the link. Applications on the display PC will control the eyetracker to start subject setup and calibration, but the operator uses the *EyeLink* PC's keyboard to do setup, remotely control the application, and handle problems. The *EyeLink* tracker contains much of the interface needed for this, simplifying applications on the display PC.

Link/Peripheral: Here the display PC controls all of the *EyeLink* functions, and the *EyeLink* keyboard need not be used. The link supports all the commands and status transfer for this, but this mode requires the most application program complexity.

The *EyeLink* interface consists of a set of menu and monitor screens, which may be navigated by means of link commands or keys. Each screen and its access to other screen through keys is illustrated below (Figure 4).

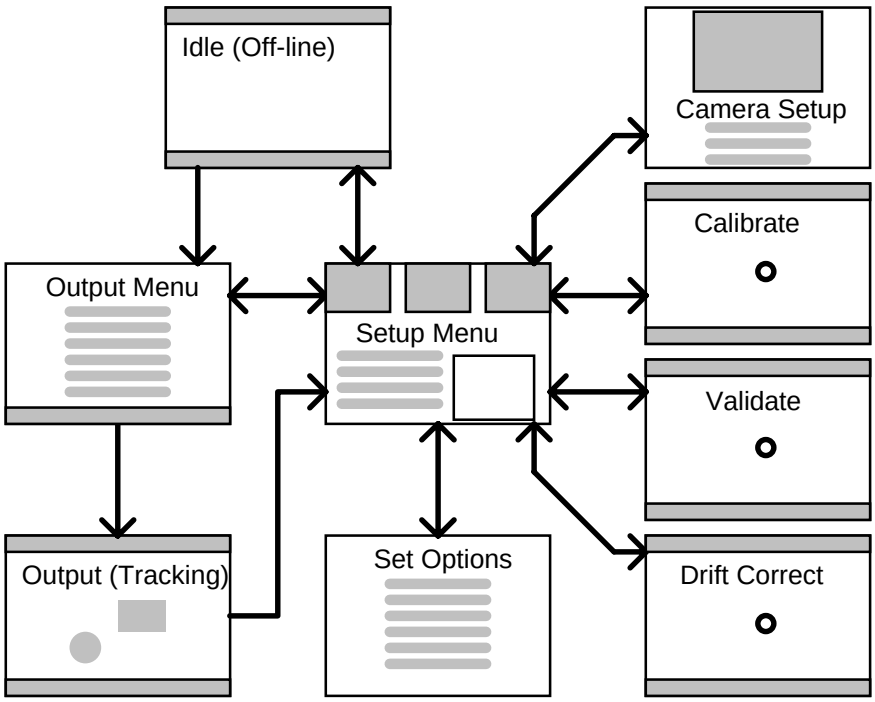

Figure 14: Menu Overview of EyeLink Program

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 grey 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: any mode is accessible by link control. 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 here. Important keys are also listed at the top of each mode screen display. From any mode, the key combination 'CTRL+ALT+Q' will exit the EyeLink tracker program.

Idle (Off-line):

In this mode, no image processing is performed, and operations like file transfers and drawing graphics for the tracking screen can be performed. Any graphics drawn on this screen are automatically saved for the tracking screen, to be used as a reference for the gaze cursor.

KEYS: 'ENTER' to Setup menu or 'O' to Output menu.

Setup Menu: This is the central menu for most *EyeLink* setup functions. From this menu the tracking cameras can be set up, calibrations performed and tested, and options set. Almost every other mode can be accessed from this screen.

KEYS: 'ENTER' to Camera Setup (Image) mode, 'S' to Set Options menu, 'O' to Output menu.

Camera Setup (Image): This menu displays a greyscale image from one headband camera. It can be used to position cameras and set thresholds.

KEYS: 'ENTER' or 'ESC' return to Setup mode.

Set Options Menu: The key menu on this screen can be used to set the most useful *EyeLink* options, including calibration type, eye tracking modes, analog output mode, and so on.

KEYS: 'ENTER' or 'ESC' return to Setup mode.

Calibrate: The pupil-to-gaze calibration is performed from this screen. Targets are presented for the subject to fixate on the subject PC through the link, and feedback graphics are presented to the experimenter on this display. The calibration is automatically checked when finished, and diagnostics given.

KEYS: 'ENTER' or 'ESC' returns to Setup mode.

Validate: The pupil-to-gaze calibration is checked for accuracy from this screen. Targets are presented for the subject to fixate on the subject PC through the link, and feedback graphics are presented to the experimenter on this display. The accuracy is scored when finished, and diagnostics given.

KEYS: 'ENTER' or 'ESC' returns to Setup mode.

Drift Correction: A single calibration target is presented for the subject to fixate on the subject PC through the link, and the subject's fixation is used to correct for any drift in system accuracy.

KEYS: 'ENTER' or 'ESC' returns to Setup mode.

Output Menu: A menu of options allows opening and closing data (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.

KEYS: 'ENTER' or 'O' to Output mode, 'ESC' returns to Setup mode.

Output (Tracking): 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.

KEYS: 'ESC' returns to Setup mode. This may be locked out when running experiments, and the safer 'CTRL+ALT+A' combination must be used. This key will pop up a menu defined by the application on the subject PC, allowing subject setup corrections, and trial abort or repeats.

You can experiment with these modes to see what they do, but to actually learn to use *EyeLink*. you must set up a real subject, as described in section 4.3.

4.3 EyeLink Options

You can use a mouse on the *EyeLink* PC to simulate an eye to practice calibration and tracking alone. Use the '-m' command line option to enable the mouse.

4.3.1 Configuration Files and Experiment Directories

Most other EyeLink options are selected by editing the configuration files (*.INI) or by sending commands from the subject PC via the Ethernet link. The configuration files are loaded by Eyelink from the current directory (where 'EYELINK' was typed from) and if not found there, from the directory containing the tracker program (C:\EYELINK\EXE).

This makes it possible to create custom configurations for experiments without editing the files in the C:\EYELINK\EXE directory, by placing the modified versions of the *.INI files in the directory where the EyeLink tracker is invoked from. This is also where data (*.EDF) files will be written to, so it makes sense to create a directory on the EyeLink operator PC for each experiment, copy ant configuration files into this directory that need to be modified for this experiment, and to invoke the tracker from this directory.

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

EYELINK.INI	The main configuration file, pulls 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.
HARDWARE.INI	EyeLink hardware settings.
PHYSICAL.INI	Monitor, head-camera and display pixels resolution settings. All physical setup and simulation settings.
CALIBR.INI	Calibration and validation settings, error checking.
DATA.INI	Controls data written to EDF files, link.
LINK.INI	Link format, data control, update timing, image sending.
PARSER.INI	On-line parser data types, configuration, saccadic detection thresholds.
KEYS.INI	Special key function defenitions, default user menus.
BUTTONS.INI	Hardware definition of buttons, special button functions.
ANALOG.INI	Analog output hardware interface configure, clock/strobe control.
IOCTRL.INI	Status/command port, analog clock output.
MOUSE.INI	Mouse simulation driver configure.
DISPLAY.INI	Display resolution, on-screen eye image display, auto-save of recording graphics.
IMGPROC.INI	Image processor parameters, blink rejection.
ERRORS.INI	Error detection thresholds.

Table 1: EyeLink Configuration Files

4.4 Analog Data Types

Position data and pupil size data are available in several types, which are selectable through the *EyeLink* tracker's options menu (see the *EyeLink* user documentation for details).

For pupil size, either pupil area or pupil diameter may be monitored. These are very high-resolution measurements, 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:

Pupil: This measurement is the raw pupil-center position as measured by the image-processing system. This measurement is available without performing an eye-tracking calibration, but cannot use the *EyeLink* 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* setup, and for the -5V to +5V output range, it is 5V*tan(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* 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. SR Research is committed to developing *EyeLink*-based applications to support most eye-tracking research applications, and will make available software-development tools for using the *EyeLink* data-link and file formats. We will keep you informed of improvements in documentation and availability of these tools.

5. *EyeLink* Utilities User's Guide

This chapter describes the *EyeLink* test and demonstration utilities included on the subject PC. These include demonstration link programs, eye-data viewers, an *EyeLink* control and data transfer TSR, and a standalone calibration and control utility.

In the companion document “EyeLink EDF files”, utilities for listing, translating and viewing the EDF data files are discussed, along with the text-based ASC file format and viewer utilities.

5.1 Subject PC EyeLink Utilities

The utilities found in the subject PC's C:\SIMLINK\EXE directory are summarized below. Some of these may also be found in the operator PC's C:\EYELINK\EDF directory as well.

SIMTSR.EXE — A small TSR that implements an Ethernet connection to the *EyeLink* software. It implements control and status monitoring functions, allows calibration targets to be displayed by the PC in synchrony to the *EyeLink*'s display, and allows eye data (samples and events) to be streamed from the tracker at 250 samples/second. It has a data buffer to prevent data loss, and implements a microsecond-resolution clock. It also handles image transfer, and key and button echoing between computers

TRACK.EXE — A simple demonstration of the operation of the *EyeLink* tracker and link, useful for subject setup practice and demonstrations. The software "tracks" the operation of the *EyeLink* tracker, displaying appropriate targets and displays for each tracker function. It allows calibration, drift correction, test screen presentation with real-time gaze cursor. It does not require SIMTSR to be loaded.

By using the '-b' command line option, TRACK.EXE may be run on a third PC connected to the network to demonstrate the broadcast listening feature.

DEMO.EXE — A simple experiment template for the *EyeLink* tracker and SIMTSR link. It performs system setup, and two trials with pre-trial drift correction. It allows trial abort and restart, and implements a real-time gaze cursor. SIMTSR must be loaded to run the program, and all source code is included in the developer's kit.

REMCAL.EXE — A small program to run from the subject PC to calibrate and remotely control the *EyeLink* tracker. This allows existing analog-input programs to be used with *EyeLink*'s gaze-position data. It can also open and close data files, and transfer these from the operator to subject PC. It not require SIMTSR to be loaded.

EDFVIEW.EXE — A mouse-driven graphical viewer for the EDF files created by EyeLink. It can display multiple-trial recordings of monocular or binocular data. See the EDFVIEW manual for imformation on its use.

EDFSCAN.EXE
EDFSORT.EXE
EDF2ASC.EXE — A set of utilities to translate and check EDF files. See the EDF Files Manual for details..

5.2 EyeLink Communication TSR: SIMTSR.EXE

This is a small (20K plus data buffer) TSR that implements an Ethernet connection to the *EyeLink* tracker system. It implements control and status monitoring functions, allows calibration targets to be displayed by the PC in synchrony to the *EyeLink*'s display, and allows eye data (samples and events) to be streamed from the tracker at 250 samples/second. It has a data buffer that holds 1 to 8 seconds of data to prevent loss.

Other features implemented through SIMTSR are:

- Eye-camera image transfer to the subject PC.
- File copying from the operator PC to subject PC.
- Monitoring of buttons and keys on the operator PC.
- Remote-control of the EyeLink tracker by echoing local keys.
- Sending commands to and reading status of the EyeLink tracker.
- Sending of messages to be timestamped and logged in the data file.
- A microsecond-resolution clock.
- Reading EyeLink tracker's timestamp clock.

The command-line options of SIMTSR.EXE are:

-r	Removes TSR from memory.
-n <size>	Installation: allocate buffer of <size> bytes. Default is 10000 bytes samples, with 5000 to 40000 possible. Each sample requires 12 to 46 bytes of memory, varying with its data contents
-i <vector>	Installation: interrupt to install TSR at. The default TSR interrupt is 0x62.
-p <vector>	Installation: interrupt that Ethernet packet driver is installed at. The default is 0x60.

Table 2: Command-line Options of SIMTSR.EXE

SIMTSR must be installed before running DEMO.EXE, or writing programs with the developer's kit. More details on this kit are provided in the Programming with SimLink manual.

5.3 EyeLink Mode-Tracking Demonstration: TRACK.EXE

TRACK.EXE is a simple demonstration of the operation of the *EyeLink* tracker and SIMTSR link, useful for subject setup practice and demonstrations. The software "follows" the operation of the *EyeLink* tracker, displaying appropriate targets and displays for each tracker function. A sample session using TRACK.EXE is discussed in Chapter 3.

The SIMTSR link does not need to be installed before using TRACK, as it contains an embedded version. Before starting TRACK, the *EyeLink* tracker must be running on the tracker PC, and connected with the Ethernet cable. After successful connection, the tracker will be placed in Off-line (idle) mode, and a blank screen with a mode identifier message in the top left corner will be displayed. The *EyeLink* keyboard is used to control the operation of the tracker, to perform camera setup, calibration, and recordings .

From Off-line mode, press ↵ (ENTER) on the operator PC's keyboard to enter Setup mode, and follow the key menus (and instructions in Chapter 3) to set up cameras, perform calibration or validation, and to start recording. During calibration, validation, or drift correction, targets are displayed on the local PC's display as required. In these modes, pressing the spacebar on the display PC's keyboard acts like the *EyeLink* ↵ key or its spacebar, triggering acceptance of fixations on calibration targets. Pressing the 'ESC' key on the display PC's keyboard will cause TRACK to force the *EyeLink* tracker into Off-line mode, and pressing 'ESC' with the tracker in Off-line mode will disconnect from the tracker and exit TRACK.

When the tracker's Output mode has been entered (press 'O' twice), TRACK remotely controls the EyeLink tracker to perform a recording session. It draw a screen of text or grid of targets on the subject PC's display, and tracks gaze position with a gaze cursor. The cursor uses data sent over the link to let the subject see his own eye movements, and can be toggled on and off with the 'G' key from the display PC.

A background display of boxes (one per word of the text screen) is displayed on the Output mode screen of the operator PC. It serves as a reference for the gaze-position cursor, to let the operator see problems with tracking accuracy. This feedback is very important in real eye-tracking situations, where the display of a gaze cursor on the display screen is not desirable.

TRACK causes the tracker to create a data file DATA.EDF on the operator PC's hard disk. By using the Output menu ('O' key) a new data file may be created. When TRACK exits, the last data file created will be copied over the link to the subject PC. This may be viewed with EDFVIEW.EXE after exiting from the EyeLink software.

5.3.1 Broadcast-Data Tracking Demonstration

By starting the TRACK application with the '-b' option on a third PC connected into the Ethernet link, a broadcast-data function can be demonstrated. In this mode, TRACK listens in on control and data between the EyeLink tracker and TRACK.EXE or EXPT.EXE running on the subject PC. TRACK does not itself initiate any action, only follows the operation of the session on the link. It replicates the calibration-target display of the subject PC, and also uses the link data to move a gaze-position cursor. Image display may not work properly, if the listener PC is significantly slower that the active PC.

5.4 Eye-Tracking Experiment Template: DEMO.EXE

The *EyeLink* system was designed with the needs of eye-movement researchers in mind, and thus has many features that are not found in other eye tracking systems. DEMO was created to demonstrate the use of *EyeLink* in a typical eye-tracking experiment, showing how the tracker and experimental application interact. Typically, the experimenter starts the experimental application, then controls the experiment from the *EyeLink* keyboard and display. Full source code for DEMO.EXE is included with the *SIMLINK* developer's kit.

DEMO begins by switching the EyeLink tracker to Setup mode, where camera setup and calibration can be performed. Validation can also be performed to

check calibration accuracy, and calibration repeated if needed. Appropriate targets will be displayed on the display PC's monitor as required. Pressing the 'ESC' key on the *EyeLink* keyboard exits Setup mode. This is sensed by DEMO, and allows the experiment itself to begin.

DEMO then presents three eye-tracking trials (display presentation and data recording block), with a drift correction before each trial. Because this is to be used as a template for real experiments, no gaze-position cursor is implemented. Instead, each trial will wait for any tracker button to be pressed, or will time out after 20 seconds. You can modify DEMO from the files in the developer's kit, which also contains code to add a real-time gaze cursor.

The use of trial-abort control through user-defined menus is also demonstrated. By default, the tracker allows interruption of recording sessions by pressing the 'ESC' key on the operator PC's keyboard. Because this could accidentally interrupt experimental data collection, EXPT locks out this key, and trials may be aborted through the key combination 'CTRL+ALT+A'. This automatically displays a user menu on the operator PC display, allowing the Setup menu to be used to re-calibrate the subject, to restart or skip the current trial, or to abort the experiment. All this requires careful co-operation with the experimental application on the subject PC, which makes the source code for DEMO.EXE especially valuable.

During each trial, DEMO will have the tracker write to a data file DATA.EDF on the operator PC's hard disk. After DEMO terminates, it transfers the file over the link to the subject PC. This file may later be viewed with EDFVIEW.EXE after exiting from the EyeLink software.

The source code for DEMO is included with the *SIMLINK* developer's kit. By modifying this code, almost any experiment can be performed. The major changes would involve adding experiment-specific display drawing, a trial-sequencing control file, and sending of messages to the EyeLink tracker to be logged in the EDF file for use during analysis. See the 'EyeLink EDF Files' document for more information.

5.5 Remote Control and Calibration Utility: REMCAL.EXE

To allow *EyeLink* to be used with existing applications that do not have link and calibration target display support, a method is needed to perform calibrations. REMCAL is such a utility, and can be called from Windows, from DOS program-execution shells within applications, or before running applications. REMCAL is designed to complement the use of analog-data output for compatibility with older applications. Since high-resolution data is

also available through the link and TSR, the analog option is obviously most useful for compatibility with existing analog-input applications.

REMCAL is also useful as a remote-control program for eye tracking experiments. It can perform setup and drift corrections, start and stop recording, open and close data files, and transfer files to the subject PC. Using a DOS batch file, it is possible to run experiments with any display software, providing:

- Time synchronization of the data file and display events are not important.
- Buttons are not required to control the display software or sequence.
- Delays between actions (as programs load and the link is opened) are tolerable.

When EyeLink is used as an analog-output tracker with existing limbus-tracking applications, subject calibration is required to allow use of the *EyeLink* head-position compensation system. This small program may be run before and between recording sessions to perform subject setup and calibration. The program initiates the *EyeLink* Setup mode or drift correction, then displays calibration targets on the local PC's display. After the setup is completed, the tracker is switched to Output mode, starting the flow of analog data.

While the analog output data will be reasonably accurate for determining screen gaze position, most existing analog-input tracking software will also perform at least a two-point calibration. This is potentially useful: the second calibration eliminates need for drift correction, and helps properly scale the *EyeLink* data. The calibration of the *EyeLink* system must still be performed to pre-linearize the eye-position data and allow correction subject head motion.

The use of SIMTSR is not required with REMCAL.EXE, saving on valuable memory. The local PC must be connected to the *EyeLink* PC via the Ethernet cable, and the EyeLink software must be running. During setup, calibrations and (optionally) drift corrections, `REMCAL` switches the display to the 640x480 16-color VGA mode, and switches to DOS text-mode on exit. Other operations do not change the video mode.

Command-line options to `REMCAL.EXE` determine what operations it will perform. Several options may be specified: each will be performed in the order in the command line. Options such as '-b', '-q' and '-c' which configure the setup operation must be first. The '-q' option will prevent error messages from messing up carefully formatted displays.

FILE OPERATIONS

-o <name>	Opens EDF file on the operator PC called <name>.EDF

-x	Closes any open EDF file on the operator PC
-i	Enters *EyeLink* Off-line (Idle) mode, stopping recording.
-g	Copies last-opened EDF data file from operator PC to local PC. Closes any open files
-g <name>	Copies file <name> from operator PC to local PC. Closes any open files.
	RECORDING
-rs	Switches *EyeLink* to Output (record) mode, sends samples only to any open EDF file.
-re	Switches *EyeLink* to Output (record) mode, sends events only to any open EDF file.
-rse	Switches *EyeLink* to Output (record) mode, sends samples and events to any open EDF file.
-i	Enters *EyeLink* Off-line (Idle) mode, stopping recording.
	SETUP, DRIFT CORRECTION
-s	Enters *EyeLink* Setup mode, displays calibration targets till 'ESC' is pressed from the *EyeLink* menu to exit Setup mode.
-d <X> <Y>	Performs a drift correction, displaying a target at (X,Y) on the display. Pressing ESC starts Setup menu
-dq <X> <Y>	Performs a drift correction, does not disturb display
-b	Beeps before target display in calibration, validation, and drift correction
-c <fg> <bg>	Sets foreground, background colors for target display screens. Default foreground is 0 (black), background is 7 (light grey)
-q	When first option, prevents display of connect and erroir messages.
	COMMANDS
-f <file>	Sends commands from a text file to the *EyeLink* tracker, for setting experimental configuration

Table 3: Command-line options of REMCAL.EXE

The most useful command combinations for analog output are:

- Enter Setup mode (to perform calibration), then Output mode for analog data output:

```
REMCAL -s -r
```

- Perform drift correction (target at display center), then enter Output mode for analog data output:

```
REMCAL -d 320 240 -r
```

A typical session for recording data to an EDF file, using external display software might be:

- Enter Setup mode (to perform calibration), open a data file:

```
REMCAL -s -o data.edf
```

- For each trial, perform drift correction (target at display center), then start recording samples and events. Run display software. Stop recording:

```
REMCAL -d 320 240 -rse
<run display software>
REMCAL -i
```

- When done, close data file and transfer across link:

```
REMCAL -x -g
```