Human Response to Different Adaptive Optic Flow Stimuli

Prasad Ghude

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Approved by

Arun Ross, Ph. D., Committee Chairperson
J. Vernon Odom, Ph. D.
James D. Mooney, Ph. D.

Lane Department of Computer Science and Electrical Engineering
Morgantown, West Virginia
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Keywords: Optic flow, Focus of Expansion (FOE), Threshold, Precision, Bias.
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ABSTRACT

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Prasad Ghude

Low vision is a major health problem, especially among the elderly; their reduced vision impairs their ability to navigate, impairs their ability to perform activities of daily living independently, and places them at greater risk for accidents and deaths. This work presents an innovative approach for understanding the optic flow processing ability of low vision patients wherein an application has been developed using Microsoft Visual Basic and a series of tests have been written. These tests are adaptive in nature and have been generated using OpenGL to better represent their 3-dimensional nature.

The term “Optic flow” refers to the change in visual input as a person moves through an environment. It is the apparent visual motion we experience as we move through an environment and it is a common visual phenomena that we experience everyday. Optic flow can be characterized by several components, including radial flow either inward or outward, laminar flow to the left or to the right, rotation or curl which is clockwise or counterclockwise motion, and deformation or change in shape.

Significant research has been performed to investigate how humans, animals and insects use optic flow to navigate through the world. However, not much research has been conducted to study the impact of eye diseases, age or environmental conditions on optic flow detection. In our efforts, we have designed six different types of simulated optic flow stimuli and these have been integrated to a graphical user interface in order to understand and analyze the general response of humans to these stimuli. The parameters of our model such as the number of dots, their lifetime, speed, etc. may be varied through the graphical user interface to produce desired visual patterns on the screen. The subject indicates the position of the FOE (Focus of Expansion) by clicking the left or the right mouse button. The basic idea is to obtain and analyze the response of humans with different visual impairments to various adaptive optic flow stimuli.

Keywords: *Optic flow, Focus of Expansion (FOE), Threshold, Precision, Bias, Offset and Offset Step Size.*

DEDICATION

It is with tremendous love and pride that I dedicate this work to my parents, Vinod and Vaishalee Ghude. Their persistent support and encouragement has been a source of inspiration for me. They have committed and sacrificed so much of their own lives to make mine better. I also thank my sister, Pranjali Ghude for encouraging and supporting me in every step that I have taken in my life. I would also like to extend my sincere appreciation towards all my friends for their belief in my abilities and for being my family away from home.

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TABLE OF CONTENTS

1. Objective 1

2. Motivation to the problem..... 1

3. What is Optic flow ?..... 2

3.1 Assessment of Optic flow thresholds-threshold determination 2

4. Method and approach..... 3

5. Justification of the approach..... 4

6. Innovativeness about the research and this application..... 5

7. System requirements..... 6

8. Overview on the application 7

9. Basic design of the GUI 8

10. Performing the set up procedure..... 10

11. Different kinds of files..... 10

11.1 Default files 11

11.2 Data Files 11

11.3 Parameter files..... 14

11.4 Executable files..... 15

12. Typical experimental session 15

13. General and test specific parameters 19

13.1 General parameters 20

13.2 Test specific parameters 25

14. Tests and results 42

14.1 Experiment 1 - Detection of Optic flow 42

14.2 Experiment 2 - Detection of Curl or rotation in flow 44

14.3 Experiment 3 - Detection of motion parallax in laminar flow 46

14.4 Experiment 4 - Effects of adding coherent, laminar Motion 48

14.5 Experiment 5 - Effects of adding speed noise to the Optic flow 51

14.6 Experiment 6 - Effects of adding directional noise to Optic flow 53

15. Limitations of the application & improvements 56

16. Challenges encountered 56

17. Implementation and future work 57

18. References 58

19. Appendix – Papers published 59-92

LIST OF FIGURES

FIGURE 1: SAMPLE OPTIC FLOW STIMULUS. 2

FIGURE 2: SYSTEM ORGANIZATION. 6

FIGURE 3: TYPICAL GRAPHICAL USER INTERFACE. 9

FIGURE 4: SAMPLE DATA FILE FOR OPTIC FLOW TEST. 13

FIGURE 5: PARAMTER FILE FOR OPTIC FLOW TEST. 15

FIGURE 6: 2-CORRECT 1-INCORRECT RULE 21

FIGURE 7: 3-CORRECT 1-INCORRECT RULE 22

FIGURE 8: SINGLE STAIR CASE (WITH FEEDBACK) 23

FIGURE 9: DOUBLE STAIR CASE (WITHOUT FEEDBACK) 24

FIGURE 10: OPTIC FLOW TEST INTERFACE 25

FIGURE 11: CURL TEST INTERFACE 28

FIGURE 12: LAMINAR FLOW TEST INTERFACE 30

FIGURE 13: OPTOLAMINAR TEST INTERFACE 33

FIGURE 14: SPEED NOISE TEST INTERFACE 36

FIGURE 15: DIRECTIONAL NOISE TEST INTERFACE 39

FIGURE 16: ANALYSIS OF OPTIC FLOW TEST 44

FIGURE 17: ANALYSIS OF CURL OR ROTATIONAL FLOW TEST 46

FIGURE 18: ANALYSIS OF LAMINAR FLOW TEST 48

FIGURE 19: ANALYSIS OF OPTOLAMINAR TEST 50

FIGURE 20: GAUSSIAN CURVE 52

FIGURE 21: ANALYSIS OF SPEED NOISE TEST 53

FIGURE 22: ANALYSIS OF DIRECTIONAL NOISE TEST 55

Human Response to Different Adaptive Optic Flow Stimuli

1. Objective

The objective of the problem report is to develop a portable software application package to obtain and analyze human responses to several adaptive optic flow stimuli. An application has been developed using Microsoft visual basic at the front end and several adaptive optic flow patterns have been generated using OpenGL and C languages at the back end. The results of the tests are recorded in output files for further analysis and graphical analysis of the tests is also provided. We thus examine the impact of reduced vision on higher order visual perceptual abilities; and the relationship of differences in perceptual abilities on the performance of simulated and real tasks of everyday living.

2. Motivation to the problem

Low vision is a major health problem, especially among the elderly; their reduced vision impairs their ability to navigate, impairs their ability to perform activities of daily living independently, and places them at greater risk for accidents and deaths. Thus, vision is important to maintain a healthy, active life as one ages. Maintaining good vision is important to maintain independence and experience good quality of life; many of our daily activities, such as walking or driving to the store, cooking, or gardening have strong visual demands. Consequently, impaired vision is one of the most important causes of impaired ability to perform daily activities for Americans aged 70 years and older **[1]**. This emphasizes the relative importance of evaluating factors correlated with good mobility and control of visual motor tasks in low vision patients and thus serves as a motivation behind this problem report.

Also, none of the studies conducted so far have assessed the ability of low vision patients to detect radial optic flow information, although a few did attempt an indirect measure of optic flow information (**[2], [3]**). These previous studies have been unable to provide evidence that the information presented in them has had an effect in evaluating patients for orientation and mobility training, modifying training based on individual's abilities or in assessing its effectiveness.

3. What is Optic flow?

Optic flow is the change in visual input as a person moves through the environment. It has been characterized by several components, including radial flow either inward or outward, laminar flow to the left or to the right, rotation or curl which is clockwise or counterclockwise motion, and deformation or change in shape. In an optic flow field, there is a stationary point from which all of the changes flow. This stationary point, also called the *Focus of Expansion* (FOE), is the point toward which the person is heading. The pioneer work on detection of optic flow by Gibson (**[4], [5], [6]**) has been identified as a major determinant of people's ability to successfully navigate in their environment. Gibson's major insight was that detecting the FOE was sufficient to determine where a person was heading.

In the basic optic flow test, the FOE of dots starts out at some distance from the fixation and slowly as the user responds correctly, it starts shifting towards the center red fixation depending on the value of the offstep (also called Offset Step Size). The FOE moves away from the center fixation if the user does not respond correctly.

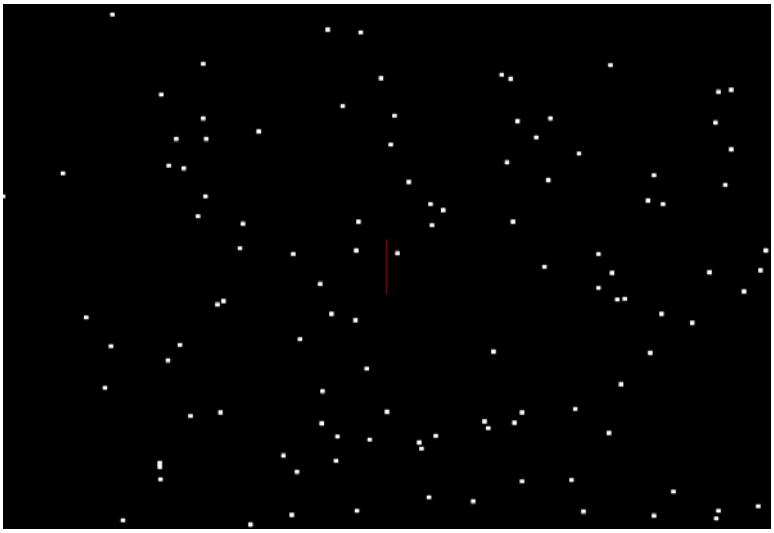


FIGURE 1: SAMPLE OPTIC FLOW STIMULUS.

3.1 Assessment of Optic flow thresholds-threshold determination

The observer looks at a video monitor. A sparse cloud of dots originating from a point (source) and moving outwards is presented on the screen. This source point, also called as the focus of expansion can be located to the left or to the right of the center of the video

monitor. Following stimulus presentation, the person is presented with a fixation target at the center of the screen and asked to indicate by pressing the left or right button of a mouse whether the FOE is to the left or to the right of the target. Using a dual, adaptive thresholding technique which employs a 2 down 1 up rule (described on page 24), we gradually bring the FOE closer to the center of the screen. Two values are identified, one being the mean for the staircase detecting leftward deviations of the target and one being the mean for the staircase detecting rightward deviations. The midpoint between these two is the Point of Subjective Equality (PSE, Constant Error) and represents the person's bias in estimating the location of the FOE. One half of the distance between the two points estimates the precision of the person's estimate of FOE location. Thus measuring the bias and precision of FOE judgments provides a more complete picture of patients' performance.

4. Method and approach

This problem report presents an innovative approach for understanding the optic flow processing ability of low vision patients wherein an application has been developed to record and analyze the optic flow processing ability of patients with different kinds of visual problems. An application has been developed using Visual Basic and a series of optic flow tests have been written in OpenGL, which have been integrated with the GUI that aid in analyzing patients with different kinds of visual problems.

A Graphical User Interface (GUI) has been developed which launches several low vision tests written in OpenGL. These optic flow tests have been written using OpenGL for analyzing the visual abilities of patients with low vision and the impact of visual abilities on their daily lives. These tests are adaptive in nature, i.e., they tend to be difficult/easy based on the user's response and are written in OpenGL since the visual patterns have to be represented in a 3-dimensional environment.

***Overview on Optic Flow module*:**

The optic flow module determines people's bias and precision for detecting optic flow. The basic method is similar to others in the literature **[7]**, but the module has some added features. Stimuli may be presented with or without a target fixation, with or without masks of arbitrary size and location, and responses may be obtained with or without

feedback on correctness. Dots can have a variable lifetime and their speed can be varied by adjusting corresponding parameters. The size and the number of dots can also be varied to produce varying visual patterns. The application permits the addition of directional noise, speed noise, rotational or laminar motion, optic flow with laminar flow, etc.

5. Justification of the approach

The application is designed to test visual performance in six types of visual discrimination: *Optic flow, Curl or rotation in flow, laminar motion, optic flow with simultaneous laminar flow (also called as OptoLaminar flow) and effects of speed and directional noise on optic flow.* In most of the tests, observers are presented with a stimulus presentation following which they respond with a left or right click. In some of these tests, observers are tested with and without noise using a two-alternative, spatial forced-choice tracking rule. This rule basically decreases the offset by a certain predefined value called offstep (described on Page 30) only after two correct responses, and increases the offset after one incorrect response.

The ultimate goal is to obtain estimates of “threshold”, “precision" and “bias of the observer”. This gives us an idea about the “detection efficiency” of the observer. These set of optic flow tests are performed with and without "noise." The meaning of noise varies with the tests; however, in most of the tests, the user specifies the standard deviation of a Gaussian distribution from which the noise is drawn. In almost all the experiments, the user has the option of viewing the stimuli with or without a fixation and the user’s response may be obtained with or without feedback on correctness. In some experiments, the no feedback option produces two different values, one being the mean for the staircase detecting leftward deviations of the target and the other being the mean for the staircase detecting rightward deviations. The midpoint between these two is the Point of Subjective Equality (PSE, Constant Error) and represents the person’s bias in estimating the location of the FOE. One half of the distance between the two points estimates the precision of the person’s estimate of FOE location. Thus measuring the bias and precision of FOE judgments provides a more complete picture of patients’ performance. In some experiments such as the basic optic flow, the observer has the

choice of viewing the stimuli with or without masks of arbitrary size and location. By obtaining detection scores at several noise levels, it is possible to estimate observer efficiency and internal noise. In all the above experiments, the parameters such as the number of dots, their lifetime, movement, etc are variable and can be changed to produce desired stimulus on the screen. These studies will be the first to use low-vision subjects to determine their ability to detect the focus of expansion.

6. Innovativeness about the research and this application

The problem report presents an innovative approach to understanding the optic flow processing ability of low vision patients where a series of tests have been written using OpenGL and are being integrated to a Graphical User Interface for analyzing patients with different kinds of visual problems such as age-related macular degeneration, glaucoma, or diabetic retinopathy.

It is innovative primarily because of the subject population. These studies will be the first to use low-vision subjects to determine their ability to detect the focus of expansion. All the previous studies on focus of expansion have determined the bias, not the sensitivity to focus of expansion. In other words, these tests only determined whether the FOE is to the left or right. However, the calculation of precision was not discussed.

Visual problems such as age-related macular degeneration, glaucoma and diabetic retinopathy represent the three major reasons for visual loss in older Americans and they differ substantially in their visual characteristics. Another reason for selecting these patient groups is the expected differences between the groups in their visual acuity and pattern of visual field loss, and what these convey about optic flow processing. Patients with age-related macular degeneration may be expected to have primarily central field loss and more severely reduced visual acuity. Patients with glaucoma may be expected to have primarily mid-peripheral loss and peripheral loss with relatively well preserved visual acuity. Lastly, patients with diabetic retinopathy have a more varied pattern of loss that may be described as a patchy field loss. This application is the first of its kind being developed for evaluation of low vision and is funded in part by the NEI (National Eye Institute) and the US Air Force. These studies will serve as a foundation for more realistic future studies, which examine the mobility of low vision patients in simulated

environments and investigate the role of higher order visual functions in the control of everyday activities in low vision patients.

Certain assumptions have been made. These are

1. Subjects are capable of responding to optic flow and its components.
2. Their performance will be impaired compared to the people with normal vision.
3. The magnitude of impairment will differ for different categories of patients.
4. The magnitude of impairment will differ based on the visual characteristics of individual patients.

These assumptions appear reasonable given that low vision patients have reduced velocity discrimination **[2]** and detection of motion shear **[3]**.

7. System requirements

The test battery requires a computer equipped with a suitable graphics card. The test battery is designed to run under any version of Microsoft windows. All the required files will be copied by the installer. An appropriate version of OpenGL and GLUT libraries will also be installed by the installer. If the system already has a newer version, the files may or may not be replaced by the old ones depending on the installer's choice. The required minimum configuration is Pentium II Processor, 64 MB RAM, 4 MB Graphics card, 200 MB of free hard disk space. The recommended system configuration is Pentium 4 processor 2.0 GHz, 256 MB RAM, 16 MB Graphics card, 2GB free hard disk space.

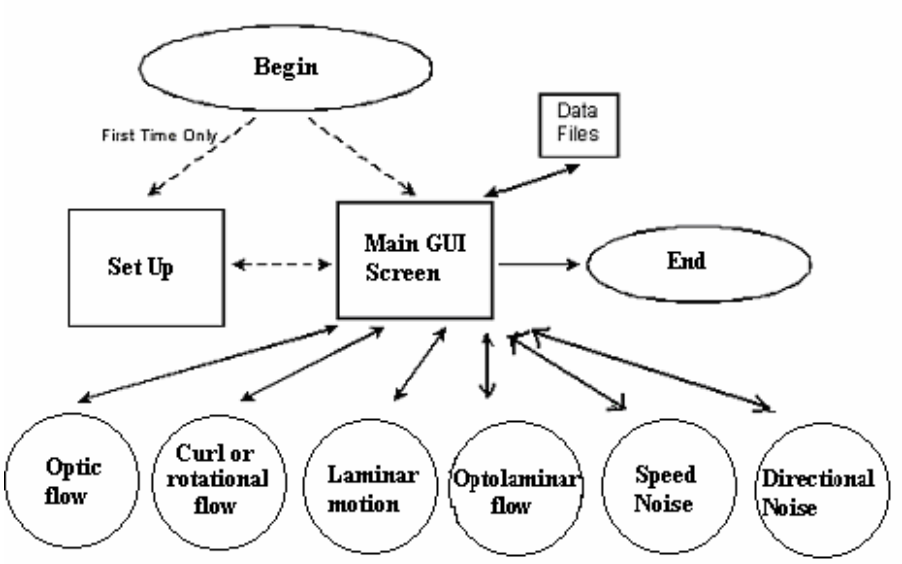


FIGURE 2: SYSTEM ORGANIZATION.

8. Overview on the application

The application consists of six open GL programs written using Microsoft Visual C++, all of which are operated through a common Graphical User Interface (GUI) (see FIGURE 3). The application called Higher Order Visual Perception shifts between the GUI and the GL programs (to run the experiments). The application has been developed using Microsoft Visual Basic 6.0 at the front end which invokes several low vision tests written in OpenGL. The graphical analysis of these tests is also presented in the GUI. The results of the tests are stored in an output file to be viewed later for further analysis. The tests are adaptive and hence, tend to be difficult or easier based on the user's response. Each test has a specific objective where in the observer views visual patterns on the screen and responds with a left click or a right click. There are four basic types of files that are associated with the application for running a session correctly - **.**exe(executable), **.**def(default), **.**par(parameter) and output Data files(test specific).

The executable files contain the executable code for that particular test. For example woptic.exe is called for running the Optic Flow test. Similarly wcurl.exe is called by the GUI to run the curl or rotational flow test.

The default files contain the default start up values for the test specific and general parameter values that are initially loaded by the GUI. They are accessed by the VB shell to load the default values into the GUI. If the .def file is not found, then zeros are loaded into the GUI. Thus, in short the default files contain a set of values for the general or test-specific parameters and the GUI initially looks for default files (.def) to load these predetermined default start up parameter values.

The parameter files contain values that are used by the test specific executable file to produce the desired stimuli on the screen. When a test starts from the GUI, the parameter values are saved to a "parameter file (.par)" which is read by the executable test program. The user has no direct control over the creation of these files, but can modify them with a text editor if desired or by changing the values in the graphical user interface before starting the experiment. Each file contains the predetermined parameter values set by the user, the demographic data and the name and format of a new data file to be created.

The data files contain the results of each experimental session stored in an output file to be viewed later for further analysis. The data files for each of the tests are located in a

different subdirectory. For example, the data files for Optic flow test are stored in "c:\edog\optic". The output files contain the user's response to the tests. The demographic and the test specific data are also recorded.

The different types of files are explained in detail in section 11 below.

9. Basic design of the GUI

The GUI has been developed using Microsoft Visual Basic. On start up, the user initially sees the GUI main screen. The left half of the screen is used to select one of the tests, to set the parameter values and enter the demographic data of the user such as the subject Name, ID and Condition. For graphical analysis of the user's response, the right half of the GUI contains a table and a graph which can display data and results of a particular experiment.

In a typical experimental session, the user must enter demographic data such as name, a unique ID and his condition, select a test, enter parameters values, and click on the start test button. A window pops up asking whether the parameters for a given test are correct or not. If confirmed the test starts. At this point, the program leaves the graphical MS-Windows environment. In each test, the observer views a series of two-alternative, spatial forced-choice trials. In most of the tests, following each trial, the observer indicates whether the target was to the left or to the right of the fixation mark by pressing the left or right mouse button, respectively. In case of curl or rotation of flow, the observer indicates whether the flow of dots was anti-clock wise or clockwise by pressing the left or right mouse button, respectively. For the Laminar motion test, there will be four frames with two sets of randomly placed dots. One set of dots moves to the left and the other moves to the right. The speed of dots will be faster in one direction. The observer indicates which frame of dots is moving faster by clicking the left (right) mouse button if the dots moving to the left (right) of the screen are faster. Difficulty of each trial is adjusted by means of a tracking rule and parameters set by the user. After the test runs to the specified number of track reversals, the control returns to the MS-Windows GUI.

The user may then choose to –

1) End the session,
2) Run another test,

3) Review the data from the just completed test or

4) Review data from any existing data file.

The graphical analysis of these tests is also presented in the GUI. The results of the tests are stored in an output file which can be viewed anytime for further analysis.

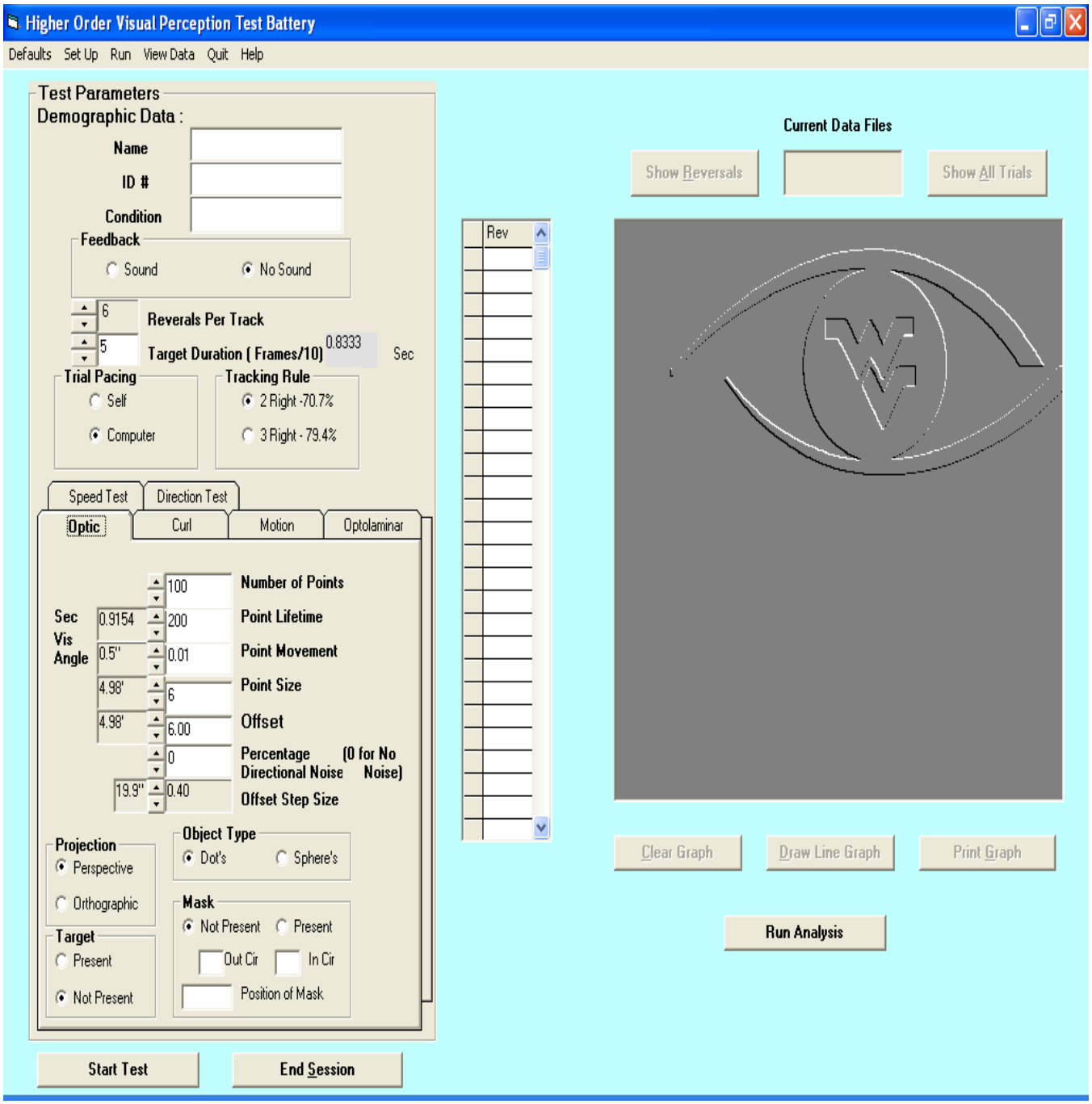


FIGURE 3: TYPICAL GRAPHICAL USER INTERFACE.

10. Performing the set up procedure

Upon launch, the GUI looks for a file named "noise.set" which contains the information related to the “Set Up” procedure. If the GUI does not find a file by this name, then it asks the user to perform the “Set Up” procedure. When the set up screen is loaded, there are five steps in performing the “Set Up” procedure:

1. Click on button “Show test pattern” to reveal a circle with two diameter lines shown – a vertical and a horizontal one. The length of the diameter is 400 pixels.
2. Adjust the height and width controls of the monitor so that the display exactly fits the screen and the vertical, horizontal diameters of the circle are of same length. This step is not necessary in most cases as the figure presented on the screen is already a circle.
3. Measure the diameter of the circle and enter the value in centimeters into the appropriate field in the upper left hand corner of the screen.
4. Enter viewing distance in centimeters into the appropriate field in the upper left hand corner of the screen. The circle diameter and viewing distance are used to convert distances in units of pixels to units of visual angle. If either or both are not entered, the tests will still run without any problem. The visual angle units are merely a convenience for the user but never directly employed by the program itself. However if not properly calibrated, the visual angle values in the GUI would be meaningless.
5. Click on the "Done" button to complete the setup procedure and return to the main screen.

The user can re-run the procedure at any time by clicking on “Set Up” menu and choosing “Create New Set Up”. The user can also re-square the screen or change circle diameter or viewing distance values. Selecting "View Current Set Up" menu item from the “Set Up” menu will reveal current parameters without making any modifications.

11. Different kinds of files

There are four basic types of files that are associated with this application for running a session correctly -.exe(executable), .def(default), .par(parameter) and an output Data file

(test specific). The contents of the .def and the .par files are either integers or floating point numbers.

11.1 Default files

Various parameter values are required for running the tests successfully, some of which are general and some of which are test specific.

There are two types of parameters-

1. General parameters common for all tests, and
2. Test specific parameters which are accessed by that particular test.

The test specific parameters can be modified in the GUI to conduct that particular experiment with desired parameters. There are seven default files, one for general parameters and one for each of the six test types. Each file contains a set of values for the general or test-specific parameters which appear in the GUI upon startup. These files are accessed by the VB shell to load the default values into the GUI. If the .def file is not found, then the GUI loads zeros into the GUI.

The “general.def” file loads general parameter default startup values common to all experiments. The default values for a specific test are stored in their respective .def files for e.g. “opticflow.def” contains the test specific defaults for the optic flow test.

In addition to creating new defaults through the GUI, the user can simply edit the default files with a text editor and change values. However, care must be taken to avoid corrupting the formatting, which would make the file unreadable to the GUI.

11.2 Data Files

All the tests when completed produce an output data file. This output file contains the user’s response to the tests. The demographic and test specific data are also recorded.

Naming Convention –

Data files are named XX#####.$$,

where XX refers to the observer initials, ##### refers to a random number which is used only as an identifier to ensure that the file has a unique name and $$ refers to the test extension: "f0" for Optic flow etc.

Example: pr33704.f0 – Optic flow test, pr412962.cm and pr412655.cm – Curl test

Above are the three data files for observer named Prasad(pr) who performed Optic flow

test once and Curl or Rotational flow test twice where 33704, 412962 and 412655 are random identifiers. The random identifier helps in distinguishing the two records collected under the same conditions.

Contents -

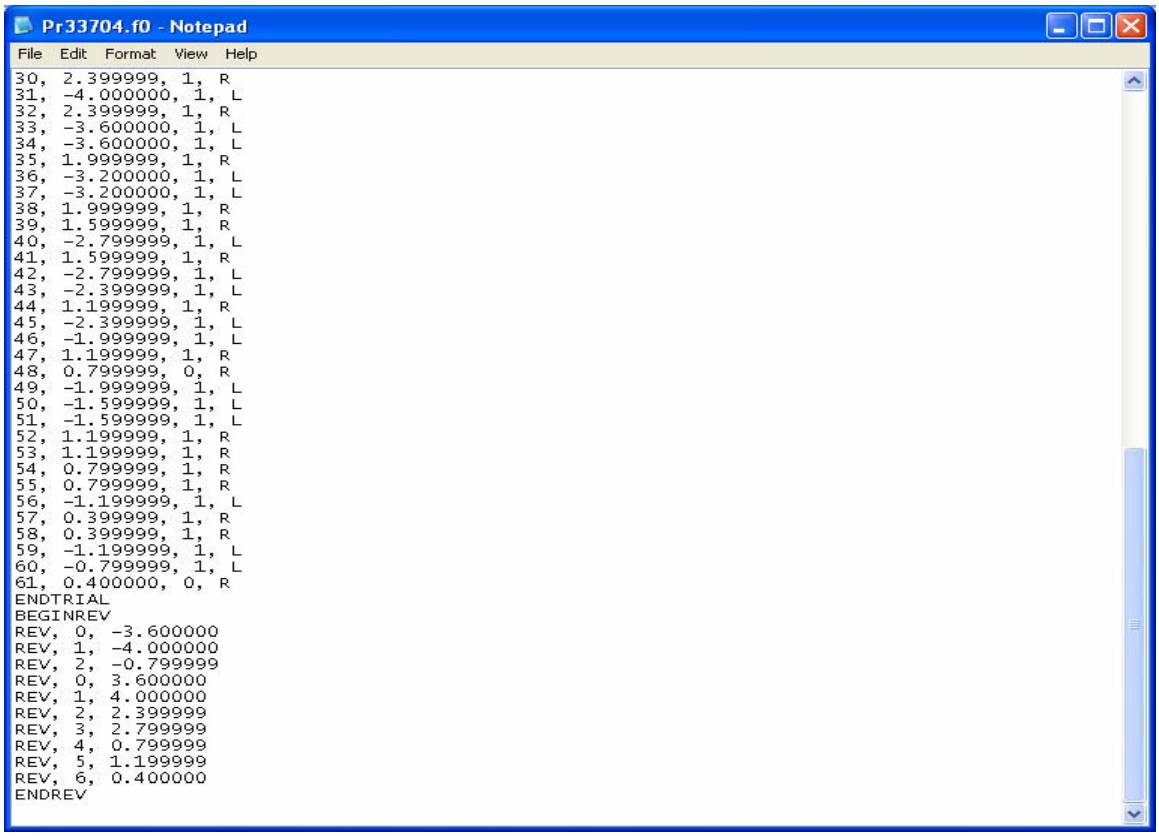
Here's a sample data file for an optic flow test – pr33704.f0 :

Pr33704.f0 - Notepad

File Edit Format View Help

```
BEGINPARAM
Subject name , Prasad Ghude
Subject ID,  999
Subject Condition , normal
Feedback , 0
Number of points , 100
Number of reversals , 2
Life Time , 200
Size of point , 6
Movement of Points , 0.010000
Projection , 1
Object type , 0
Percent of dir noise, 0
Mask , 0
Target , 0
ENDPARAM
BEGINTRIAL
1, 6.000000, 1, R
2, -6.000000, 1, L
3, 6.000000, 1, R
4, -6.000000, 1, L
5, 5.200000, 1, R
6, 5.200000, 1, R
7, -5.200000, 1, L
8, 4.400000, 1, R
9, -5.200000, 1, L
10, 4.400000, 1, R
11, 3.600000, 1, R
12, 3.600000, 0, R
13, 4.000000, 1, R
14, 4.000000, 1, R
15, 3.600000, 1, R
16, -4.400000, 1, L
17, 3.600000, 1, R
18, 3.200000, 1, R
19, 3.200000, 1, R
20, 2.799999, 1, R
21, -4.400000, 1, L
22, 2.799999, 1, R
23, 2.399999, 1, R
24, 2.399999, 0, R
25, -3.600000, 1, L
26, -3.600000, 0, L
27, -4.000000, 1, L
28, 2.799999, 1, R
29, 2.799999, 1, R
```

Continuation of the sample data file - pr33704.f0 on next page



Pr33704.f0 - Notepad

File Edit Format View Help

```
30, 2.399999, 1, R
31, -4.000000, 1, L
32, 2.399999, 1, R
33, -3.600000, 1, L
34, -3.600000, 1, L
35, 1.999999, 1, R
36, -3.200000, 1, L
37, -3.200000, 1, L
38, 1.999999, 1, R
39, 1.599999, 1, R
40, -2.799999, 1, L
41, 1.599999, 1, R
42, -2.799999, 1, L
43, -2.399999, 1, L
44, 1.199999, 1, R
45, -2.399999, 1, L
46, -1.999999, 1, L
47, 1.199999, 1, R
48, 0.799999, 0, R
49, -1.999999, 1, L
50, -1.599999, 1, L
51, -1.599999, 1, L
52, 1.199999, 1, R
53, 1.199999, 1, R
54, 0.799999, 1, R
55, 0.799999, 1, R
56, -1.199999, 1, L
57, 0.399999, 1, R
58, 0.399999, 1, R
59, -1.199999, 1, L
60, -0.799999, 1, L
61, 0.400000, 0, R
ENDTRIAL
BEGINREV
REV, 0, -3.600000
REV, 1, -4.000000
REV, 2, -0.799999
REV, 0, 3.600000
REV, 1, 4.000000
REV, 2, 2.399999
REV, 3, 2.799999
REV, 4, 0.799999
REV, 5, 1.199999
REV, 6, 0.400000
ENDREV
```

FIGURE 4: SAMPLE DATA FILE FOR OPTIC FLOW TEST.

NOTES: The contents of the data file are explained below -

- **BEGINPARM to ENDPARM:**

  Shows test conditions i.e.

  1) Observer initials, Id and condition.
  2) General parameters such as without feedback (indicated by 0), number of reversals-2 etc.
  3) Test-specific parameters such as number of points, size, lifetime, movement etc. The presence of 0 in object type indicates dots.

- **BEGINTRIAL to ENDTRIAL:** List of individual trials formatted as trial number, Offset value (difficulty level) and correctness of response. 1 means correct response on the trial and 0 means incorrect response.
- **BEGINREV to ENDREV:** List of reversals in the track formatted by reversal number and Offset level.

11.3 Parameter files

When a test starts from the GUI, the parameters are saved to a "parameter file" which is read by the corresponding C executable test program. The user has no direct control over the creation of these files, but can modify them with a text editor if desired. If the test specific parameters are changed in the GUI, they are overwritten in a .par (parameter) file which is accessed by that specific test (exe file) to produce desired pattern (stimuli) on the screen. The parameter files are named say for e.g. “woptic.par” which means that it is the parameter file for the optic flow test.

Each file contains

1) The values of the parameters set by the user,
2) Demographic data and
3) The name of a new data files to be created.

In theory, the user could execute any one of the six executable test files from DOS, provided that a parameter file exists for each test. That is, the user could type "woptic" at the DOS prompt to run the Optic flow test provided a parameter file called "woptic.par" is present.

Note the following, however. In DOS, if the parameter file is once used to run a test, it creates a data file. If a test is then run from DOS with the same parameter file, it does not create a new data file. Instead, the new test data will be appended to the previous data file. To prevent this, the user can edit the parameter file with a text editor to change the name of the data file to be created. The name of the new data file must conform to the naming convention described above; otherwise the file cannot be read by the GUI. Since this seems to be a complicated process, it is therefore not advisable to run the tests under DOS unless there is no other option.

Naming Convention -

The parameter files have the naming convention <filename>.par, where filename is “woptic”, “wcurl”, “wopticm”, “wopto”, “wspeed” and “wdirection”. Before creating a parameter file for a new test, the GUI checks to see if there is already a file by that name. If an old parameter file exists, it is first deleted. The figure on the next page shows a parameter file for optic flow test – “woptic.par”.

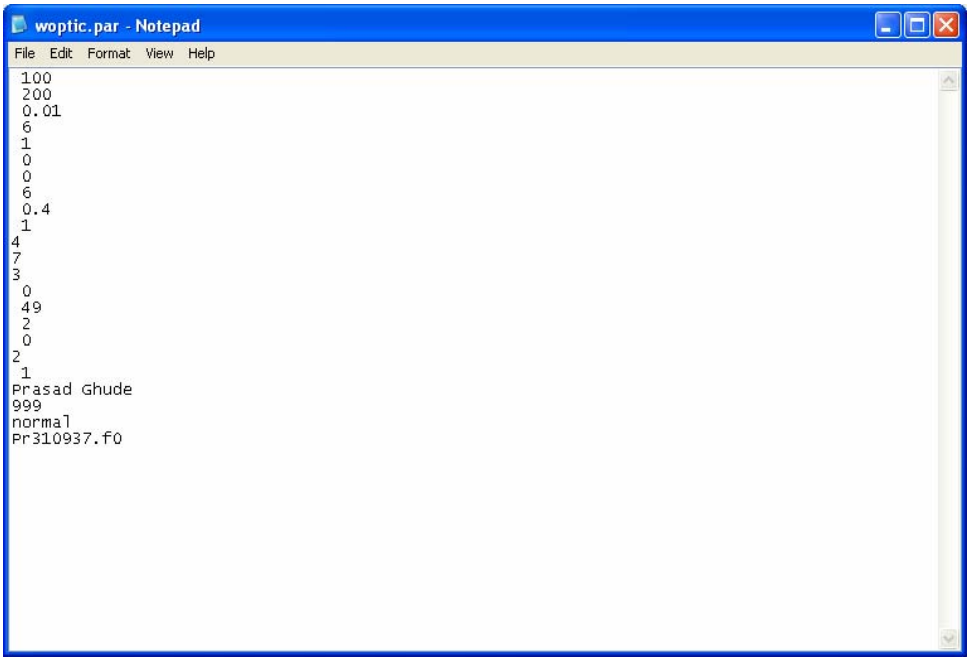


FIGURE 5: PARAMETER FILE FOR OPTIC FLOW TEST.

The values refer to various parameters for e.g. 100 refer to number of dots, 200 refer to point lifetime, 0.01 refers to point movement, 6 refers to the size of dots etc. These are nothing but the parameters present in the graphical user interface.

11.4 Executable files

These files contain the executable code for that particular test. For example woptic.exe is invoked by the GUI for running the Optic Flow test without mask. Similarly wcurl.exe is invoked by the GUI to run the curl or rotational flow test.

12. Typical experimental session

The following is a more complete description of the proceedings of a typical test session:

I. **Start session:** The user may start the application in two ways: From DOS, the user should make sure that the current directory is c:\edog and then types "edog1" at the command prompt. From Windows, the user clicks on the ‘edog1.exe’ icon located in the “c:\edog” folder or he can use the shortcut created in the Start -> All Programs -> Higher Order Visual Perception ->Higher Order Visual Perception. Tests may also be run under DOS without the GUI by typing the name of the test

program. For example for the curl test, once the user makes sure that the current directory in DOS is “c:\edog”, he can type “wcurl” at the command prompt. However, the test program will look for a special file called a “Parameter” file, which is normally created by the GUI. You can hand create these files or use ones previously created by the GUI. (See the explanation on parameter files in section 11.3). Running tests by this method is more difficult and error-prone and is probably only justified if it is necessary to conduct tests on a computer without MS-Windows.

II. **Set start up parameters:** The first time the battery is run, the user must perform the "Set Up" procedure. This creates a file named "noise.set," which the battery uses in subsequent sessions, so this procedure needs be performed only once. (See "Set Up Procedure" in section 10). However, the set up procedure may be re-run at any time by clicking on "Set Up" menu on the menu bar and then choosing "Create New Set Up" from the menu items.

III. **Enter biographic data:** A test cannot be run without entering the biographic data such as person’s name, an ID assigned to that person and the condition of the observer. The program uses the initial(s) to create and name data files. (See "Data Files” explained in section 11.2). An error message appears if the user attempts to run a test without first entering observer initials. However, once entered, the initials remain in place unless removed.

IV. **Select a test:** Upon start up, one of the tests will be chosen as a default. The default test is presently "Optic flow" but can be changed by the user. The user may select one of the six tests by clicking on one of the index tabs marked: “Optic”, “Curl”, “Motion”, “Optolaminar”, “Direction Test” and “Speed Test”. Clicking on any of the six tabs reveals a different area containing test-specific parameters.

V. **Set default, general and test-specific parameter values, if desired:** On start up,

the GUI looks for files that specify general and test-specific parameters. The default values for each test are located in the “.def” files present in the “c:\edog” folder. Thus there are seven default files – One for loading General parameters named “general.def” and one for each of the six tests. The user can accept the defaults or change them in one of the two ways given below. If the user has not previously specified the default parameters, then GUI will load 0's as defaults.

a) To change the parameter values: The user may use the up/down arrows. For some parameters, shown in white boxes, the user may also type new values directly into the box. The cursor must be moved by either tabbing to the box or by moving the pointer with the mouse to the desired point. The user may not type values directly into the grey boxes. It is necessary to restrict values of these parameters in order to avoid catastrophic errors during the visual tests. For example, one such parameter is the number of reversals which must always be even with a maximum of 20, so the up/down arrows will only allow correct values in this range. It is, however, also possible to create less serious errors by typing in the white boxes, for example cause tests to create targets which extend beyond screen bounds. In general, the user would be safe to change parameter values only with up/down arrows, or at least pre-test all conditions where numbers are directly entered. A few parameters, such as "Trail Pacing", “Tracking rule” and “Object type” are set by clicking on the desired "radio button". If changes have been made unintentionally, the user can reset to the original defaults by clicking on "Defaults" menu from the menu bar and choosing "Reload Defaults".

b) The user can also create a new set of defaults: First, enter the desired parameter values as described above. Next, go to the menu item marked "Defaults," and save the new defaults for either i) general parameters or ii) a specific test. This action creates new default files, which store the values shown on the screen as default parameters. The next time the program is started, the GUI reads these files and the new defaults will appear on the screen. Alternately, the user can modify the “General.def” file to suit his needs. If the user does not explicitly save the new defaults, all changes to parameter values will be lost upon program termination and will have to be re-entered during the next session.

VI. Starting the Desired Test: The user may start the test in one of the three ways –

1. Clicking the Start Test button located at the bottom left of the screen.
2. Using the Run Tab on the menu and then selecting the desired test.
3. Using the shortcuts for the desired test. The shortcuts for running the tests are as given below –

- Optic Flow test – Ctrl + O.
- Curl Test – Ctrl + C.
- Laminar Flow Test – Ctrl + L.
- OptoLaminar Flow Test – Ctrl + P.
- Speed Noise Test – Ctrl + S.
- Directional Noise Test – Ctrl + D.

Once the user starts the test by using any one of the above three methods, the test leaves the GUI interface and moves to the DOS mode. Two beeps signal the start of the test and a black field covers the screen. The user must click either the left or the right mouse button to start the visual display. After the visual display stops, the user is supposed to click the left or the right mouse button to indicate his response. The trials can be initiated either by the observer or automatically by the computer, i.e. the display of visual patterns is either self controlled or computer controlled.

Once the test runs the given number of reversals, the test stops and the observer data is saved to a file for later viewing. The control then moves from the DOS mode to the GUI.

VII. View data: The observer can run another test immediately or view the data produced by the just-completed test. Clicking the "Show Reversals" button produces both a table and a graph of the track's reversal points as well as the threshold obtained by averaging reversals. NOTE: Reversal "0," although shown, is not used in threshold calculation. Clicking on the "Show All Trials" button graphs all trials in the track.

The GUI permits viewing of two graph types. The default graph is a "scatter graph" of points. When there are many points, the graph can become confusing,

so the user may switch to a "line graph." The same button toggles between the two graph types. Clicking "Print Graph" prints a hardcopy of the displayed graph on the printer specified during the computer's MS-Windows set up.

To view another test data file, the user chooses "View Data" from the menu bar and then clicks "Select File...” which opens a new window. The window permits the user to select a data file for viewing. The data files for each of the tests are located in a different subdirectory. The data files for Optic flow tests are stored in “c:\edog\optic”. Each test has a specific directory in the “c:\edog” folder which contains the data files. The user clicks on the desired subdirectory to see the list of data files. There are **two ways to view the data.** First, a single click on a data file will cause the parameters for that test to appear in a box on the right. The user can change the selection by single clicking another file name, or click on the "View Data" button to graph the data. Only one file at a time may be chosen. Alternately, the user can double-click on a data file, immediately graphing the data. In either case, the window disappears and must be re-invoked to view a data file. The data files may also be viewed off-line with an ordinary text editor by opening the test specific folder and using Notepad/any text editor to open that file.

VIII. **Run another test by going to step 1, or end the session:** Optionally, the user can either end the session by clicking the “End Session” button (or by pressing the “Quit” menu on the menu bar) or he can start another test by going to the step 1. On clicking the “End Session” button/ “Quit” menu, the user quits the GUI and returns to the windows.

13. General and test specific parameters

There are two types of parameters -

- The "General" parameters, which are applicable to all the six tests, and
- "Test-specific" parameters, which are applicable to that particular test.

The general parameters appear in the upper left half of the graphical user interface, whereas the test-specific parameters appear in the tabbed areas revealed by clicking the test specific tab.

13.1 General parameters

I. Number of Reversals: Number of reversal points averaged in the test track. It is restricted to even numbers with a maximum of 20. The even number is necessary since thresholds are calculated by averaging the reversal points in the track. This parameter doesn't have units as it is a number. The number of reversals in a way decides the duration of the test as after running the test for the specified number of reversals, the test quits.

II. Target Duration: Calibrated in number of frames. Since this varies slightly with computer, the user will have to measure frame rate to obtain an actual duration value. The duration has been calibrated in terms of seconds for the computers in the Eye Institute for convenience. The unit of Duration is number of frames. Presently, it is multiplied by a factor of 10 in the background. So, 6 frames entered in the GUI would actually mean 60 frames and the display would last for a second. Please note that the frame rate varies from computer to computer and hence the user has to calibrate its equivalent in seconds.

III. Tracking Rule: Thresholds are obtained by means of a tracking procedure/rule. There are two tracking rules that are being used presently in the application. A particular tracking procedure affects the location and number of times the FOE occurs at a particular offset distance from the center.

The two tracking procedures are-

A. **2 DOWN/ 1 UP RULE (Also called 2 Correct/ 1 Incorrect rule) -** Increases difficulty by one step after two consecutive correct responses and decreases difficulty by one step after one incorrect response.
B. **3 DOWN/ 1 UP RULE (Also called 3 Correct/ 1 Incorrect rule) -** Increases difficulty by one step after three consecutive correct responses and decreases difficulty by one step after one incorrect response.

The 2-right rule estimates the 70.7% correct point on a psychometric function while the 3-right rules estimates a 79.4 correct point.

A. <u>2 DOWN/ 1 UP RULE (Also called 2 Correct/ 1 Incorrect rule)</u>

- This rule increases difficulty by one step after two consecutive correct responses and decreases difficulty by one step after one incorrect response. Below figure shows 2-correct 1-incorrct rule for a single staircase.
- As can be seen from the figure below, the FOE moves closer to the center fixation by step size, also called as the Offstep (a parameter input) after two correct responses at the same Offset value.
- Similarly, the FOE moves away from the center red fixation by the step size (Offstep) after one incorrect response.

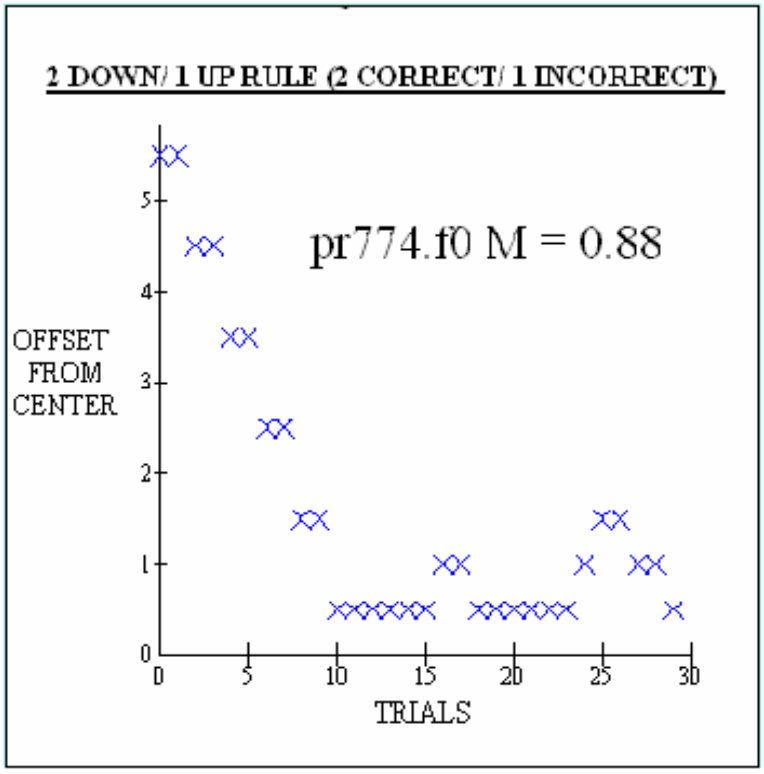


FIGURE 6: 2-CORRECT 1-INCORRECT RULE

B. <u>3 DOWN/ 1 UP RULE (Also called 3 Correct/ 1 Incorrect rule)</u>

- This rule increases difficulty by one step after three consecutive correct responses and decreases difficulty by one step after one incorrect response. Below figure shows the 3-correct 1-incorrect rule for a single stair case experiment.
- As can be seen from the figure below, the FOE moves closer to the center fixation

by offstep value only after three consecutive correct responses from the user.

- Similarly, the FOE moves away from the center by step size after each incorrect response.

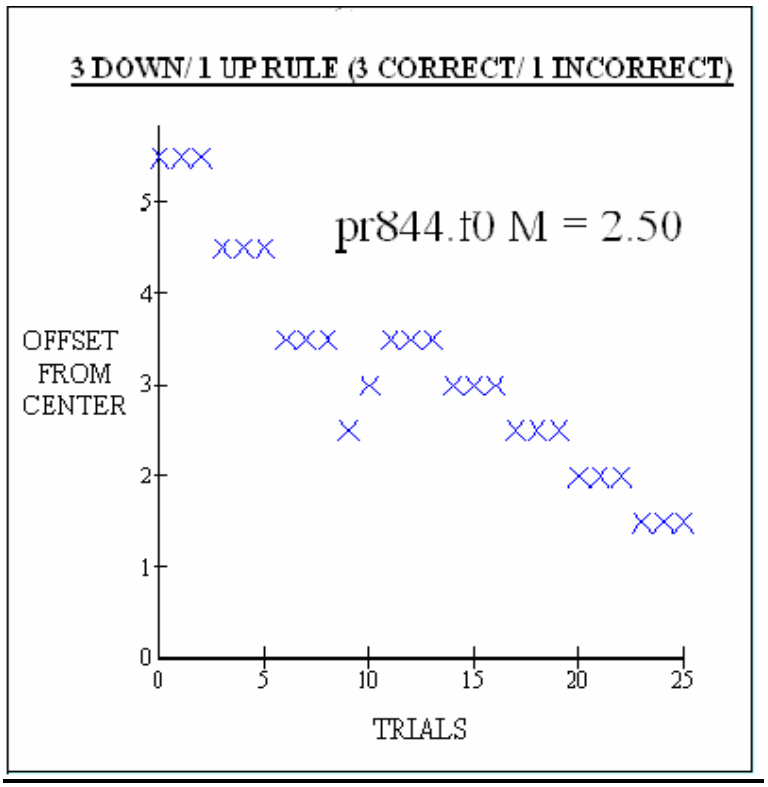


FIGURE 7: 3-CORRECT 1-INCORRECT RULE

IV. <u>Trial Pacing</u>: Trials can be initiated either by the observer or automatically by the computer. The trial may be paced by using either of the two choices –

- **Self Controlled** – The user may choose to indicate his response even before the visual display stops. Thus when he clicks left or right mouse button, the response is recorded and the subsequent visual pattern is immediately displayed on the screen.
- **Computer Controlled** – The user/observer is forced to wait till the visual display stops, only after which he can indicate his response. Once the response is recorded, the subsequent display starts. Note that any responses during the display in Computer Controlled mode are invalid and not recorded.

V. **<u>Feedback</u>:** The user may choose to conduct the test with/without feedback (sound).

- **<u>With Feedback</u>:** If the user decides to conduct an experiment with feedback on correctness and if his response is right, he hears a single beep. If the user's response was wrong, then he hears a double beep. The feedback may be of help to the user to judge future trials and in a way affect his responses. Also, conducting the experiments with feedback produces only a single staircase as shown below. The single staircase is suggested only for Curl and Laminar flow tests as there are no left and right threshold points in these experiments. Below figure shows an example of single stair case with 2 reversals for Curl test. As we can see, the observer was precise enough to get down till 10% coherence. The mean was 20% coherence for all trials. This is explained in detail in section 14.2.

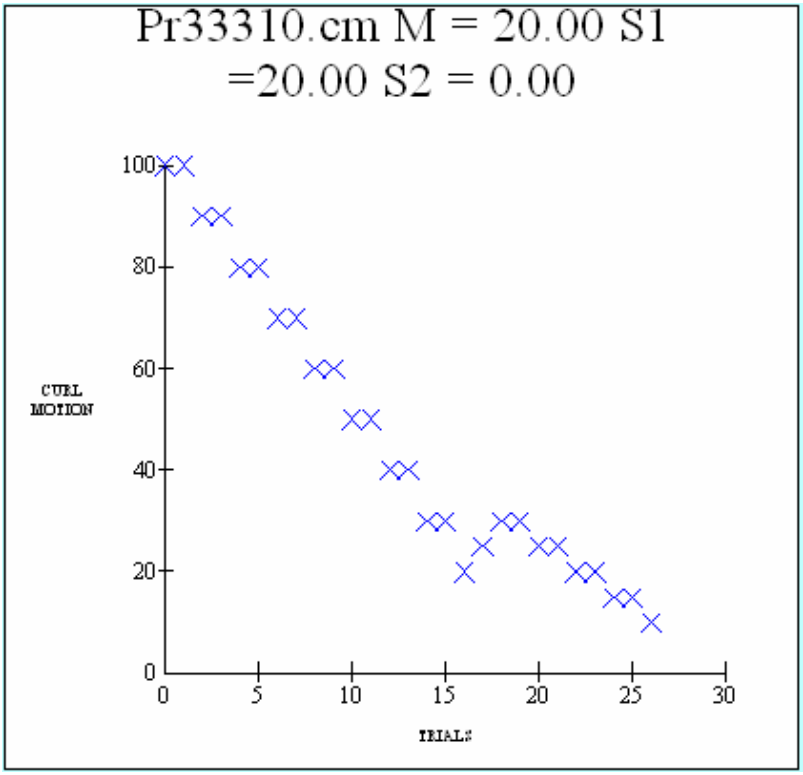


FIGURE 8: SINGLE STAIR CASE (WITH FEEDBACK)

- **<u>Without Feedback</u>:** If the user decides to conduct an experiment without feedback on correctness, then he doesn't have an idea about his performance. Its better to conduct the Optic flow, Optolaminar flow, Effects of speed and

Directional Noise without feedback This is because two values can be identified, one being the mean for the staircase detecting leftward deviations of the target and one being the mean for the staircase detecting rightward deviations. The midpoint between these two is the Point of Subjective Equality (PE, also called as Precision. PE = (S1 + |S2|)/2). The bias is calculated as the sum of these points (Bias = S1 + S2 or S1 - |S2|). Below figure shows an example of a double staircase Optic Flow experiment with 2 reversals. As we can see the observer was close enough to go down till 0.4 units (equivalent to 8 pixels) to the right of the fixation and he was able to get as close as 0.8 units (equivalent to 16 pixels) to the left of the fixation. The mean for the rightward deviations was 1.93 units (equivalent to 39 pixels) to the right of the fixation, while the mean for the leftward deviations was 2.4 units (equivalent to 48 pixels) to the left of the fixation. Thus we can say that the user had a bias of approximately 9 pixels to the left of the screen. This is explained in detail in section 14.1.

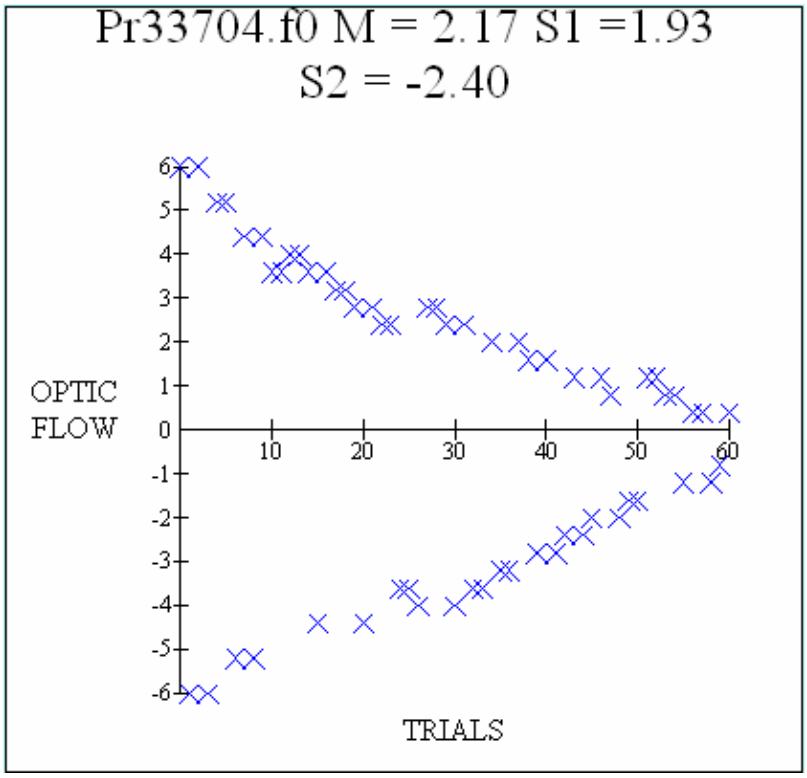


FIGURE 9: DOUBLE STAIR CASE (WITHOUT FEEDBACK)

13.2 Test specific parameters

Each of the six experiments has been written in OpenGL and is adaptive in nature, i.e. the test becomes easier or more difficult based on the user's response to the stimuli. These tests accept a parameter file as input. The parameter file is written when the user selects the desired parameter values in the graphical user interface and clicks on "Start Test" button. The test specific parameters for each of the six tests are given below –

13.2.1 Detection of Optic flow – Optic flow test

The figure below shows the test specific parameters for the Optic flow test. The parameters, their meaning, significance and limitations are as given below –

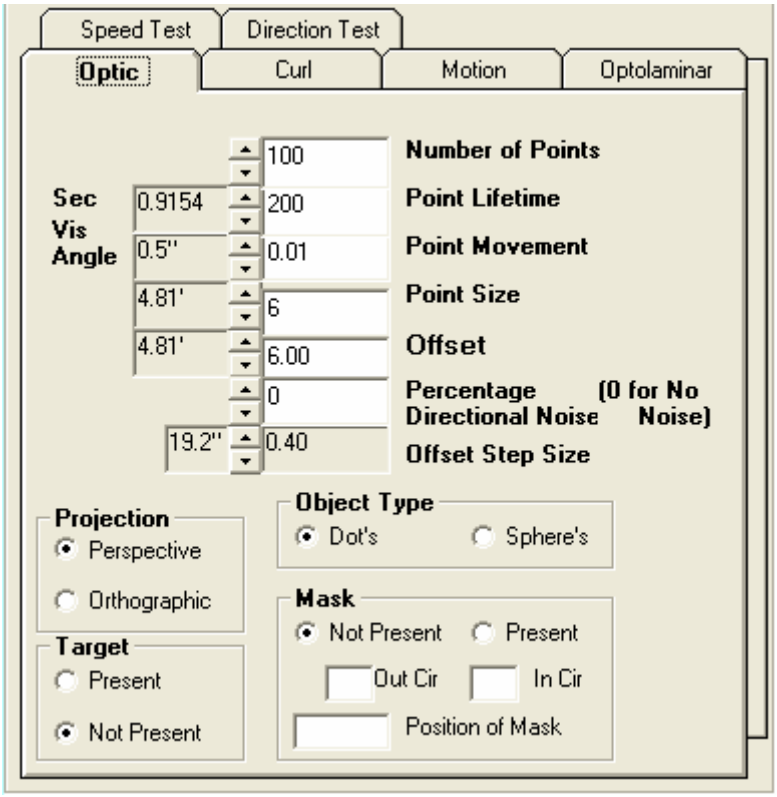


FIGURE 10: OPTIC FLOW TEST INTERFACE

Number of Points: This refers to the number of points coming out of the source. The default value is presently set at 100 i.e. 100 dots flow out of the source. If a certain number of dots move out of the viewing frustum or exceed their lifetime, the position of these dots is recomputed and they appear at the computed positions. The number of dots

can be increased or decreased using the up/down arrow in the interface. The present limit to the number of dots is set between 0 and 10000. Since this represents a number, it has no units.

Point life time: This indicates the lifetime of each dot i.e. the time for which each dot is displayed on the screen before it disappears (or) it is the value given to a frame of dots. If this value is crossed, the position of the dots is recomputed and a new set of dots are displayed at the computed positions. The unit for the lifetime is Number of Frames. If the dots move out of the viewing frustum, the position of dots is recomputed and new set of dots appear at computed positions. The default value for lifetime of a dot is presently set at 200 frames.

Point movement: This factor affects how fast the points move in the visual field. Increasing the value of this will cause the random dots to move faster in the 3-dimensional optical field. The units is units per frame (where 1 unit = 20 pixels). The present default value is 0.01 units per frame (equivalent to 0.2 pixels per frame). This parameter is multiplied by a factor and added to the point speed, pnt->s to get the new updated speed of the point. The equation used is `pnt->s = pnt->s + pnt->sign * Pnt_movement.`

Point Size: As the name suggests, it gives the size of the points flowing in the optic field. The unit of size is pixels. The present default point size is set at 6 pixels.

Offset: The value of optic flow offset (before noise added) for the first trial in the track i.e. it's the value from where the user trail begins and then it decreases or increases based on the track rule to make the task easier or harder. In other words, it's the distance away from the center fixation line from where the FOE is located. Note that 1 unit = 20 pixels. The present default value is 6 units away from the center fixation line. This means the FOE starts at a distance of 120 pixels from the center fixation and slowly moves closer to it based on the tracking rule.

Percentage directional noise: This variable determines percentage of dots, which have flow in a random direction rather than the normal optic field. Since it represents a number, it has no units.

Offset step size (Offstep): The change in offset used to make the task easier or harder. Each track starts with double the step size (Offstep) until the first error. For the remainder

of the track, the step size remains constant at the value of this parameter. Thus, this value represents the distance by which the FOE moves closer to the center fixation line. The present value is set at 0.4 units (equivalent to 8 pixels). For e.g,

If Offset = 6 units = 120 pixels,

and Offstep = 0.4 units = 8 pixels.

Then initially after two consecutive correct responses (for 2-Right rule, 1-Wrong), the FOE is at a distance of 5.2 units (equivalent to 104 pixels – a difference of 16 pixels) from the center fixation. Once the observer commits a mistake, the Offset is decreased only by 0.4 units (8 pixels) per 2 consecutive correct responses.

Projection: This parameter has two options - orthographic or perspective. It indicates the orthographic projection or perspective projection of dots in the optic field. In case of orthographic projection, the dots appear to flow along the z-axis perpendicular to xy plane i.e. the objects on the screen will appear the same size no matter how close or far away they are. Orthographic projections are commonly used in 2D scenes. In case of perspective projection, the dots appear to flow relative to one another as determined by their distance from the viewer. Perspective projections create more realistic looking scene and hence is used most often. In perspective projections, as an object gets farther from the viewer, it will appear smaller on the screen- an effect often referred to as foreshortening. The viewing volume for a perspective projection is a frustum, which looks like a pyramid with the top cut off, with the narrow end toward the user. We mostly use perspective vision for our programs since its best suited for 3d and is more realistic.

Target: This parameter dictates whether the target is present or not during the Optic flow display. We have two options to choose from- Present and Not Present.

> **Target Present:** This means that the red fixation line at the center of the screen (also called as target) is present during the visual display. This makes it easier for the observer to judge if the FOE was to the left or to the right of this center fixation since the target is always present during the visual display.
>
> **Target Not Present:** This means that the red fixation line at the center of the screen is not displayed as long as the visual pattern appears on the screen. The duration of the visual pattern is based on the number of frames selected (See target duration in section 13.1). Only before and after the end of each trial the

center fixation line appears and the observer has to judge if the displayed visual pattern's FOE was to the left or to the right of it. The intermittent occurrence of the target before and after the visual pattern display makes it difficult for the observer to judge whether the FOE was to the left or to the right of this center fixation.

Object type: It indicates the type of object flowing in the visual field. In the optic field, it could be either flow of dots or flow of spheres.

Mask: This is used to mask a certain portion of the optic flow display. Masks of arbitrary size and location can be selected based on Inner circle diameter, outer circle diameter and the position of the mask.

13.2.2 Detection of Curl or Rotation in flow – Curl or Rotational flow test

The figure below shows the test specific parameters for the Curl test. The parameters, their meaning, significance and limitations are as given below –

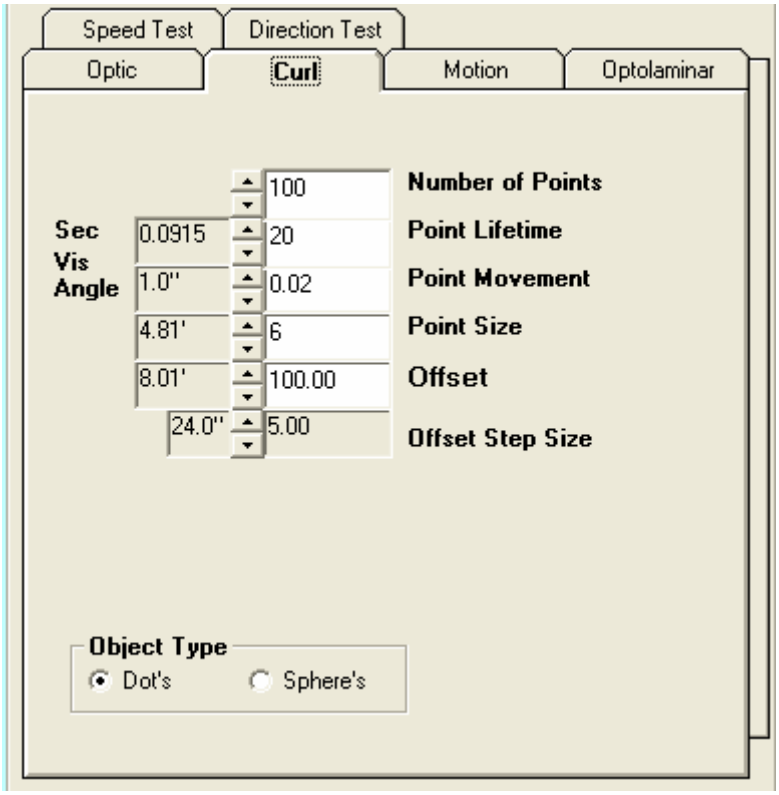


FIGURE 11: CURL TEST INTERFACE

Number of Points: This refers to the number of points moving in a particular direction per frame. The default value is presently set at 100 i.e. 100 dots flow in either clockwise or counter clockwise direction per frame. If a certain number of dots move out of the viewing frustum or exceed their lifetime, the position of these dots is recomputed and they appear at the computed positions. The number of dots can be increased or decreased using the up/down arrow in the interface. The present limit to the number of dots is set between 0 and 10000. Since this represents a number, it has no units.

Point lifetime: This indicates the lifetime of each dot i.e. the time for which each dot is present before it disappears (or) it is the value given to a frame of dots. If this value is crossed, the position of the dots is recomputed and new sets of dots are displayed at computed positions. The unit for the lifetime is Number of Frames. If the dots move out of the viewing frustum, the position of dots is recomputed and new set of dots appear at computed positions. The default value for lifetime of a dot is presently set at 200 frames.

Point movement: This factor affects how fast the points move in the circular visual field. Increasing the value of this will cause the random dots to move faster in a circular fashion. Note that the rotation of dots occurs only in a 2-d plane. The present default value is 0.01 units per frame (equivalent to 0.2 pixels per frame). This parameter is multiplied by a factor and added to the point speed, pnt->s to get the new updated speed of the point. The equation used is `pnt->s = pnt->s + pnt->sign * Pnt_movement.`

Point Size: As the name suggests, it indicates the size of the points flowing in the curl field. The unit of size is pixels. The present default point size is set at 6 pixels.

Offset: In case of curl test, the offset refers to the percentage of dots moving in a coherent fashion. The default value set presently is 100% i.e. initially all the dots flow in the same direction. Then as the user keeps responding correctly, the percentage coherence decreases by the off-step (also called as offset step size) value specified. Note that the upper limit for Offset is set at 100% as this is the point where all dots flow in coherent fashion and going above 100% has no meaning. The test can also be started from any other percentage of coherent dots instead of 100%.

Offset step size (Offstep): This is the amount by which the percentage coherence decreases or increases based on the users response. If the 2 down/1 up rule is followed, then the percentage coherence decreases by the offstep value after two consecutive

correct responses or increases after one incorrect response. So basically this factor decides how fast the percentage coherence of flowing dots decreases/increases.

Object type: It indicates the type of object flowing in the visual field. In the curl field, it could be either flow of dots or flow of spheres. We usually test subjects with dots rather than spheres.

13.2.3 Detection of Motion Parallax in Laminar flow - Laminar or Motion test

The figure below shows the test specific parameters for the laminar flow test. The parameters, their meaning, significance and limitations are as given below –

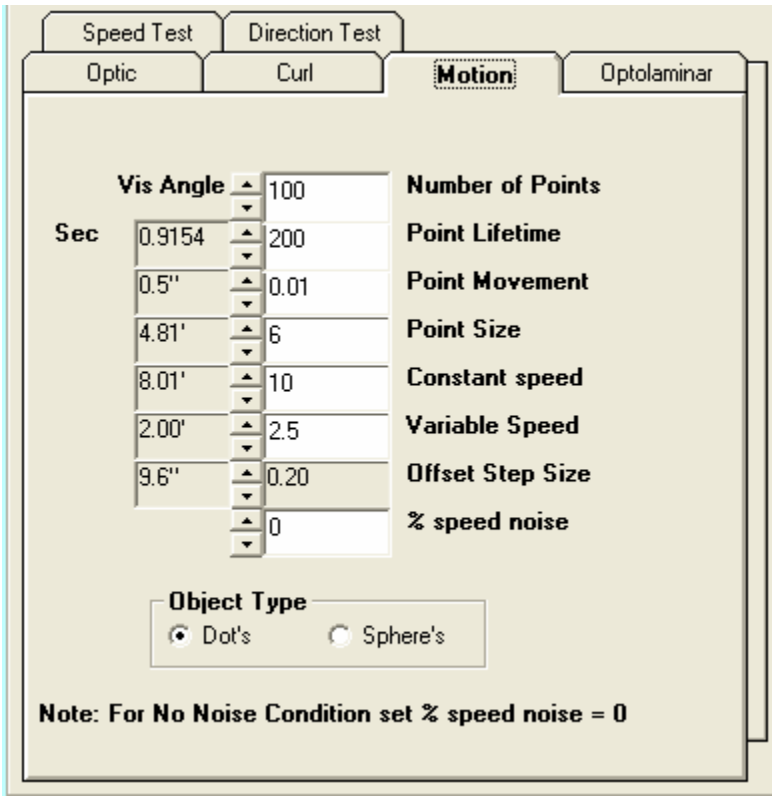


FIGURE 12: LAMINAR FLOW TEST INTERFACE

Number of Points: This refers to the total number of points moving in either direction. The default value is set at 100 i.e. 100 dots flow either to the left or to the right. If a certain number of dots move out of the viewing frustum or exceed their lifetime, the position of these dots is recomputed and they appear at the computed positions. The

number of dots can be increased or decreased using the up/down arrow in the interface. The present limit to the number of dots is set between 0 and 10000. Since this represents a number, it has no units.

Point life time: This indicates the lifetime of each dot i.e. the time for which each dot is displayed on the screen before it disappears (or) it is the value given to a frame of dots. The unit for the lifetime is Number of Frames. If the dots move out of the viewing frustum or exceed the given number of frames, the position of dots is recomputed and new set of dots appear at computed positions. The default value for lifetime of a dot is presently set at 200 frames.

Point movement: This factor affects how fast the points move in the two sets of frames. Increasing the value of this will cause the dots to move faster in both set of frames i.e. the dots will flow faster in either direction. The present value is set at 0.01 units per frame (equivalent to 0.2 pixels per frame).

Point Size: As the name suggests, it gives the size of the points flowing in the 2-d laminar field. The unit of size is pixels. The present default point size is set at 6 pixels.

Constant Speed: There are sets of dots that move at a constant speed. This speed is constant as defined by the user and their speed does not change during the experiment i.e. either of the two sets of frames moves at this constant speed. The present default value is 10 units per frame (where 2 pixels = 1 unit). Thus if the display is for 60 frames, then the point with a speed of 10 units per frame would travel = 10 units/frame * 60 frames = 600 units where 1 unit = 0.5 pixel. Thus it would travel 300 pixels in 1 second of display (60 frames). Also, note that the point lifetime is also in number of frames and if the duration is more than lifetime, the dots would disappear before travelling the expected distance. This is because in this case, the distance it travels before disappearing is governed by lifetime. Please note that the frame rate varies with computer and needs calibration.

Variable Speed: There are other sets of frame dots whose speed varies during the experiment. The user initially defines their speed. Then as the experiment progresses, their speed changes and tries to approach the constant speed of the other set of dots. The amount by which it increases is based on a parameter called Offset step size (also referred to as Offstep). So basically the speed of this set of dots starts off at a lower value (presently set at 2.5 units per frame = 75 pixels in 1 second) and increases/decreases

based on users correct/incorrect response to catch up with constant speed.

Offset step size (Offstep): This is the amount by which the variable speed changes to catch up with the constant speed. The track rule is designed such that the constant speed initially changes by a factor which is twice the Offstep until the observer makes his first mistake. Once he makes a mistake, from thereon the constant speed changes by the Offstep value. The point behind this is to quickly home in to the threshold value. Thus, the Offstep can be thought as the amount by which the variable speed changes to make the task easier or harder.

So for example consider the present default values – Constant speed = 10 units per frame and Variable speed = 2.5 units per frame. If the Offstep is 0.2 units per frame, then initially after two consecutive correct responses, then the Variable speed is 2.9 units per frame. Note that 1 unit = 0.5 pixels.

% Speed Noise: This refers to the variation in the speed of dots i.e. this refers to the percentage of dots that tend to flow at a different speed compared to either constant or variable speed. The direction of flow is either in the direction of constant speed or variable speed. Since this refers to certain number of dots, this has no units.

Object type: This is used to select either the flow of dots or flow of spheres in the laminar field. The observer can choose one of the two options by clicking on their corresponding radio button.

13.2.4 Effects of adding Coherent, Laminar Motion (Optic flow + Laminar flow) – Optolaminar flow test

Figure 13 shows the test specific parameters for the Optolaminar flow test. The parameters, their meaning, significance and limitations are as given below –

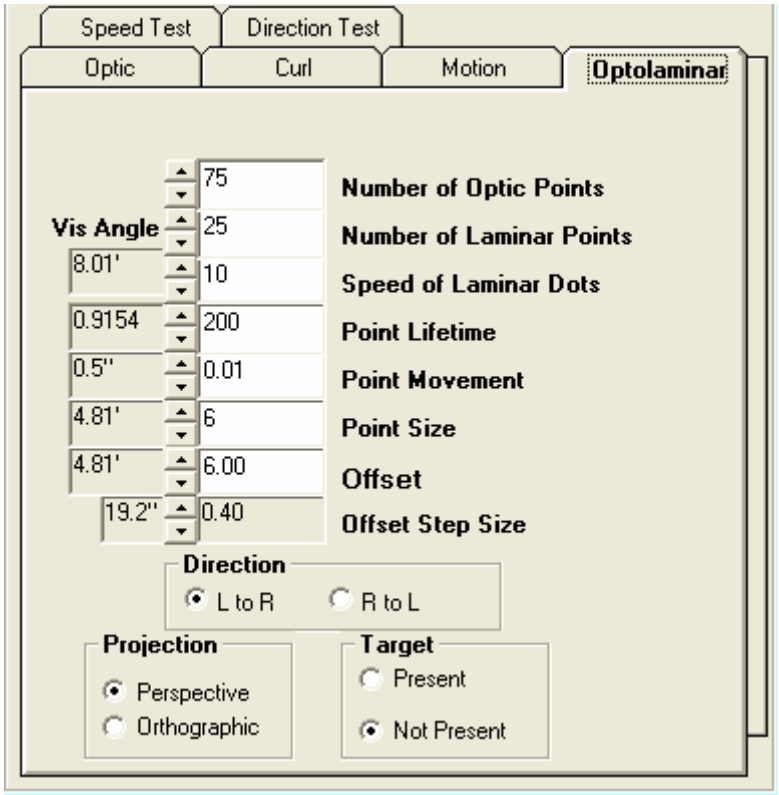


FIGURE 13: OPTOLAMINAR TEST INTERFACE

Number of Optic Points: This refers to the number of points flowing out radially from the Optic source. The default value is presently set at 75 i.e. 75 dots flow out of the Optic source. If a certain number of dots move out of the viewing frustum or exceed their lifetime, the position of these dots is recomputed and they appear at the computed positions. The number of dots can be increased or decreased using the up/down arrow in the interface. The present limit to the number of dots is set between 0 and 10000. Since this represents a number, it has no units.

Number of Laminar Points: This refers to the number of points moving in a particular direction. The flow is in a 2d plane either to the left or to the right. The default value is set at 25 i.e. 25 dots flow in a laminar 2d field either to the left or to the right. The number of dots can be increased or decreased using the up/down arrow in the interface. Since this represents a number, it has no units.

Speed of Laminar Dots: These are the sets of dots that move in a laminar 2d field at a given speed. This speed is constant as defined by the user and their speed does not change during the experiment. The present default value is 10 units per frame (1 unit =

0.2 pixels). The speed can be increased or decreased to obtain varying stimulus on the screen. Thus, if lifetime of dots = 200 frames, speed = 10 units frame, then the dot would travel a distance of (10 units/frame * 200 frames) = 2000 units = 400 pixels before the point dies out provided that the duration of display is greater than lifetime of dots.

Point life time: This indicates the lifetime of dots flowing in both 2d laminar and 3d Optic fields i.e. the time for which each dot is displayed on the screen before it disappears (or) it is the value given to a frame of dots. If this value is crossed, the position of the dots is recomputed and new sets of dots are displayed at computed positions. The unit for the lifetime is Number of Frames. If the dots move out of the viewing frustum, the position of dots is recomputed and new set of dots appear at computed positions. The default value for lifetime of a dot is presently set at 200 frames.

Point movement: This factor affects how fast the points move in the 3d optic visual field as well 2d laminar field. Increasing the value of this will cause the dots to move faster. The present default value is 0.01 units per frame (equivalent to 0.2 pixels per frame).

Point Size: As the name suggests, it gives size of the points flowing in the optic field as well as the laminar field. This is a common parameter for dots flowing in either 2d laminar field or 3d optic field. The unit of size is pixels. The default point size is 6 pixels.

Offset: This parameter refers only to the Optic dots and the FOE. The value of optic flow offset for the first trial in the track i.e. it's the value from where the user trail begins and then it decreases or increases based on the track rule to make the task easier or harder. In other words, it's the distance away from the center fixation line from where the FOE is located. Note that 1 unit = 20 pixels. The present default value is 6 units away from the center fixation line. This means the FOE of optic dots starts at a distance of 120 pixels from the center fixation and slowly moves closer to it based on the tracking rule.

Offset step size (Offstep): This parameter is useful for calculating the location of the FOE of the 3d optic dots. The Offstep is the change in offset used to make the task easier or harder. Each track starts with double step size until the first error. For the remainder of the track, the step size remains constant at the value of this parameter. Thus, this value represents the distance by which the optic FOE moves closer to the center fixation line. The present value is set at 0.4 units (equivalent to 8 pixels). For e.g.,

If Offset = 6 units = 120 pixels,

and Off-step = 0.4 units = 8 pixels.

Then initially after two consecutive correct responses (for 2-Right rule, 1-Wrong), the FOE of optic dots will be at a distance of 5.2 units (equivalent to 104 pixels – a difference of 16 pixels) from the center fixation. Once the observer commits a mistake, the Offset is decreased only by 0.4 units (8 pixels) per 2 consecutive correct responses.

Direction:

L to R / R to L: This parameter refers only to the flow of the 2d laminar dots. This parameter decides the flow of the laminar dots in the 2dimensional field. There are two radio buttons to choose from. One is L to R (i.e. the laminar dots flow from Left to Right of the screen) and the other is R to L (i.e. the laminar dots flow from the Right to the left of the screen).

Projection: This parameter has two options - orthographic or perspective. It indicates the orthographic projection or perspective projection of dots in the optic field. In case of orthographic projection, the dots appear to flow along the z-axis perpendicular to xy plane i.e. the objects on the screen will appear the same size no matter how close or far away they are. Orthographic projections are commonly used in 2D scenes. In case of perspective projection, the dots appear to flow relative to one another as determined by their distance from the viewer. Perspective projections create more realistic looking scene and hence is used most often. In perspective projections, as an object gets farther from the viewer, it will appear smaller on the screen - an effect often referred to as foreshortening. The viewing volume for a perspective projection is a frustum, which looks like a pyramid with the top cut off, with the narrow end toward the user. We mostly use perspective vision for our programs since its best suited for 3d and is more realistic.

Target:

This parameter dictates whether the target is present or not during the visual display. We have two options to choose from- Present and Not Present.

> **Target Present:** This means that during the optic and simultaneous laminar flow display the red fixation line at the center of the screen (also called as target) is present. This makes it easier for the observer to judge if the FOE was to the left or to the right of this center fixation.
>
> **Target Not Present:** This means that the red fixation line at the center of the

screen is not displayed as long as the visual pattern appears on the screen. The duration of the visual pattern is based on the number of frames selected. Only before and after the end of each trial the center fixation line appears and the observer has to judge if the displayed visual pattern's FOE was to the left or to the right of it. The intermittent occurrence of the target before and after the visual pattern display makes it difficult for the observer to judge if the FOE was to the left or to the right of this center fixation.

13.2.5 Effects of adding Speed Noise to Optic flow – Speed Noise test

The figure below shows the test specific parameters for the Speed Noise test. The parameters, their meaning, significance and limitations are as given below –

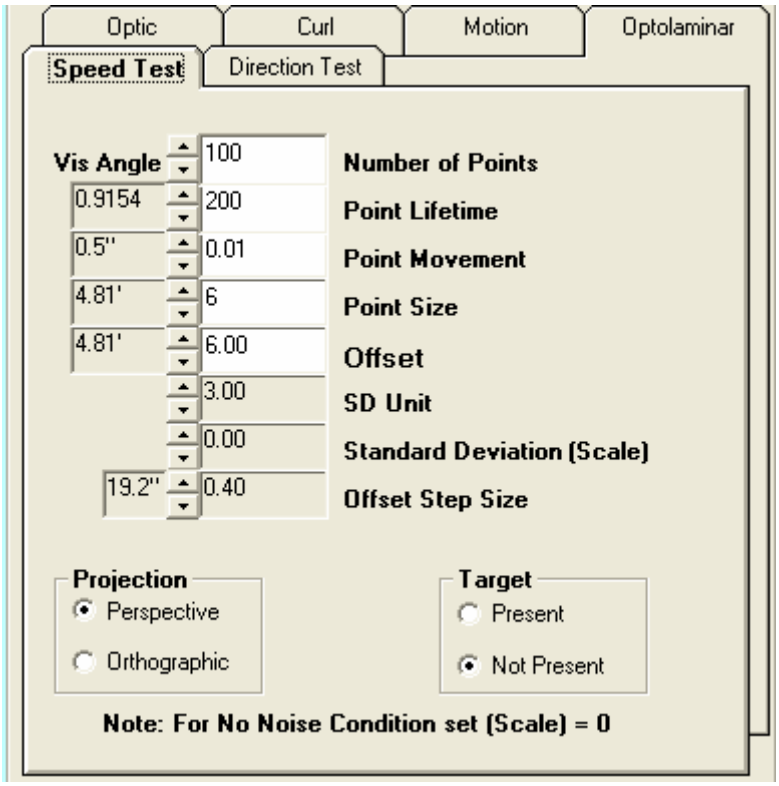


FIGURE 14: SPEED NOISE TEST INTERFACE

<u>Number of Points</u>: This refers to the number of points coming out of the source. The default value is presently set at 100 i.e. 100 dots flow out of the source. If a certain number of dots move out of the viewing frustum or exceed their lifetime, the position of

these dots is recomputed and they appear at the computed positions. The present limit is set between 0 and 10000. Since this represents a number, it has no units.

Point life time: This indicates the lifetime of each dot i.e. the time for which each dot is displayed on the screen before it disappears (or) it is the value given to a frame of dots. If this value is crossed, the position of the dots is recomputed and a new set of dots are displayed at the computed positions. The unit for the lifetime is Number of Frames. If the dots move out of the viewing frustum, the position of dots is recomputed and new set of dots appear at computed positions. The default value for lifetime of a dot is 200 frames.

Point_movement: This factor affects how fast the points move in the visual field. Increasing the value of this will cause the random dots to move faster in the 3-dimensional optical field. The units is units per frame (where 1 unit = 20 pixels). The present default value is 0.01 units per frame (equivalent to 0.2 pixels per frame). This parameter is multiplied by a factor and added to the point speed, pnt->s to get the new updated speed of the point. The equation used is `pnt->s = pnt->s + pnt->sign * Pnt_movement.`

Point Size: As the name suggests, it gives the size of the points flowing in the optic field. The unit of size is pixels. The present default point size is set at 6 pixels.

Offset: The value of optic flow offset (before noise added) for the first trial in the track i.e. it's the value from where the user trail begins and then it decreases or increases based on the track rule to make the task easier or harder. In other words, it's the distance away from the center fixation line from where the FOE is located. Note that 1 unit = 20 pixels. The present default value is 6 units away from the center fixation line. This means the FOE starts at a distance of 120 pixels from the center fixation and slowly moves closer to it based on the tracking rule.

SD Unit: This parameter actually decides the variation in the speed of dots from the mean speed. This basically describes the percentage of dots that would flow between a particular speed range. In other words, it describes the clipping region for the speed of dots. For example if the mean speed is 6 and the SD Unit = 3.0 and the scaling factor is 1 unit, then nearly 66% dots will have speeds between 5 and 7; nearly 95% dots speed would be between 4 and 8; and nearly more than 99% of the dots will have a speed between 3 and 9.

Standard Deviation (Scale): This is the factor by which the Gaussian curve gets broadened. In other words this decides the vast range in speeds. For example, if mean = 6; SD Unit = 3 and scale =1; then nearly more than 95% dots will have speeds between 4 and 8. If the scaling factor is 2; then nearly more than 95% dots will have speeds ranging between 2 and 10. Thus we have more variability in speed for a given Standard deviation.

Offset step size (Offstep): The change in offset used to make the task easier or harder. Each track starts with double the step size (Offstep) until the first error. For the remainder of the track, the step size remains constant at the value of this parameter. Thus, this value represents the distance by which the FOE moves closer to the center fixation line. The present value is set at 0.4 units (equivalent to 8 pixels). For e.g.,

If Offset = 6 units = 120 pixels and Offstep = 0.4 units = 8 pixels,

Then initially after two consecutive correct responses (for 2-Right rule, 1-Wrong), the FOE is at a distance of 5.2 units (equivalent to 104 pixels – a difference of 16 pixels) from the center fixation. Once the observer commits a mistake, the Offset is decreased only by 0.4 units (8 pixels) per 2 consecutive correct responses.

Projection: This parameter has two options - orthographic or perspective. It indicates the orthographic projection or perspective projection of dots in the optic field. In case of orthographic projection, the dots appear to flow along the z-axis perpendicular to xy plane i.e. the objects on the screen will appear the same size no matter how close or far away they are. Orthographic projections are commonly used in 2D scenes. In case of perspective projection, the dots appear to flow relative to one another as determined by their distance from the viewer. Perspective projections create more realistic looking scene and hence is used most often. In perspective projections, as an object gets farther from the viewer, it will appear smaller on the screen- an effect often referred to as foreshortening. The viewing volume for a perspective projection is a frustum, which looks like a pyramid with the top cut off, with the narrow end toward the user. We mostly use perspective vision for our programs since its best suited for 3d and is more realistic.

Target: This parameter dictates whether the target is present or not during the Optic flow display. We have two options to choose from- Present and Not Present.

> **Target Present:** This means that during the optic flow display the red fixation line at the center of the screen (also called as target) is present. This makes it

easier for the observer to judge if the FOE was to the left or to the right of this center fixation since the target is always present during the visual display.

Target Not Present: This means that the red fixation line at the center of the screen is not displayed as long as the visual pattern appears on the screen. The duration of the visual pattern is based on the number of frames selected (See target duration above). Only before and after the end of each trial the center fixation line appears and the observer has to judge if the displayed visual pattern's FOE was to the left or to the right of it. The intermittent occurrence of the target before and after the visual pattern display makes it difficult for the observer to judge whether the FOE was to the left or to the right of this center fixation.

13.2.6 Effects of adding directional noise to Optic flow – Directional Noise test

The figure below shows the test specific parameters for the Directional Noise test. The parameters, their meaning, significance and limitations are as given below –

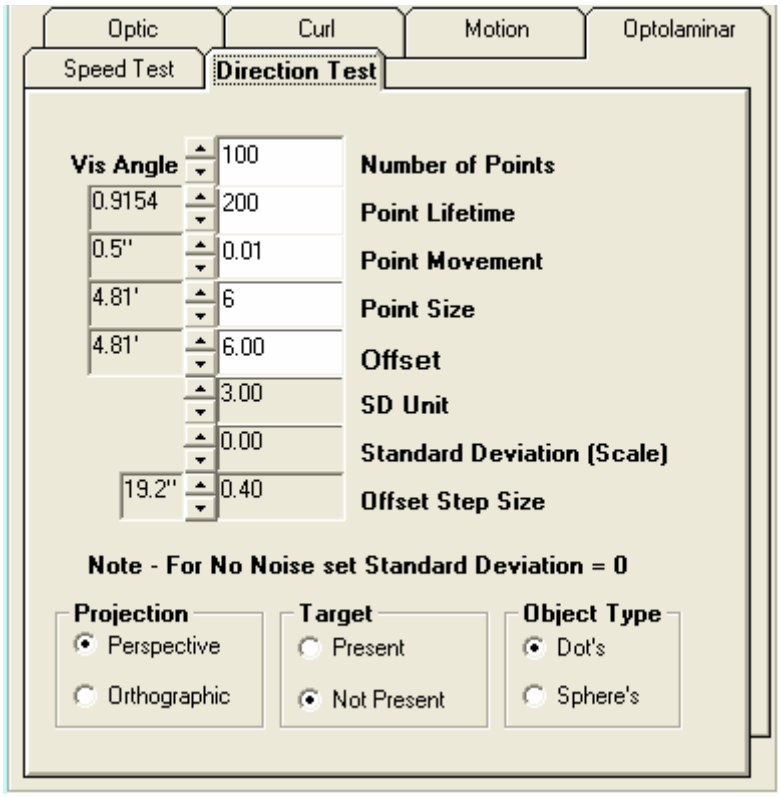


FIGURE 15: DIRECTIONAL NOISE TEST INTERFACE

Number of Points: This refers to the number of points coming out of the source. The default value is presently set at 100 i.e. 100 dots flow out of the source. If a certain number of dots move out of the viewing frustum or exceed their lifetime, the position of these dots is recomputed and they appear at the computed positions. The number of dots can be increased or decreased using the up/down arrow in the interface. The present limit to the number of dots is set between 0 and 10000. Since this represents a number, it has no units.

Point life time: This indicates the lifetime of each dot i.e. the time for which each dot is displayed on the screen before it disappears (or) it is the value given to a frame of dots. If this value is crossed, the position of the dots is recomputed and a new set of dots are displayed at the computed positions. The unit for the lifetime is Number of Frames. If the dots move out of the viewing frustum, the position of dots is recomputed and new set of dots appear at computed positions. The default value for lifetime of a dot is presently set at 200 frames.

Point movement: This factor affects how fast the points move in the visual field. Increasing the value of this will cause the random dots to move faster in the 3-dimensional optical field. The units is units per frame (where 1 unit = 20 pixels). The present default value is 0.01 units per frame (equivalent to 0.2 pixels per frame). This parameter is multiplied by a factor and added to the point speed, pnt->s to get the new updated speed of the point. The equation used is `pnt->s = pnt->s + pnt->sign * Pnt_movement.`

Point Size: As the name suggests, it gives the size of the points flowing in the optic field. The unit of size is pixels. The present default point size is set at 6 pixels.

Offset: The value of optic flow offset (before noise added) for the first trial in the track i.e. it's the value from where the user trail begins and then it decreases or increases based on the track rule to make the task easier or harder. In other words, it's the distance away from the center fixation line from where the FOE is located. Note that 1 unit = 20 pixels. The present default value is 6 units away from the center fixation line. This means the FOE starts at a distance of 120 pixels from the center fixation and slowly moves closer to it based on the tracking rule.

SD Unit: This parameter actually decides the deviation in the direction from the normal optic flow. This basically decides the amount of directional variability in the optic flow pattern. It also decides the percentage of dots that would flow at a certain deviation from the normal optic flow.

Standard Deviation (Scale): This is the factor by which the Gaussian curve gets broadened. In other words this decides the randomness in the direction of flow. Thus, as this factor is increased, we have more variability in the number and directionality of flow of dots for a given Standard deviation.

Offset step size (Offstep): The change in offset used to make the task easier or harder. Each track starts with double the step size (Offstep) until the first error. For the remainder of the track, the step size remains constant at the value of this parameter. Thus, this value represents the distance by which the FOE moves closer to the center fixation line. The present value is set at 0.4 units (equivalent to 8 pixels). For e.g.,

If Offset = 6 units = 120 pixels,

and Offstep = 0.4 units = 8 pixels.

Then initially after two consecutive correct responses (for 2-Right rule, 1-Wrong), the FOE is at a distance of 5.2 units (equivalent to 104 pixels – a difference of 16 pixels) from the center fixation. Once the observer commits a mistake, the Offset is decreased only by 0.4 units (8 pixels) per 2 consecutive correct responses.

Projection: This parameter has two options - orthographic or perspective. It indicates the orthographic projection or perspective projection of dots in the optic field. In case of orthographic projection, the dots appear to flow along the z-axis perpendicular to xy plane i.e. the objects on the screen will appear the same size no matter how close or far away they are. Orthographic projections are commonly used in 2D scenes. In case of perspective projection, the dots appear to flow relative to one another as determined by their distance from the viewer. Perspective projections create more realistic looking scene and hence is used most often. In perspective projections, as an object gets farther from the viewer, it will appear smaller on the screen- an effect often referred to as foreshortening. The viewing volume for a perspective projection is a frustum, which looks like a pyramid with the top cut off, with the narrow end toward the user. We mostly use perspective vision for our programs since its best suited for 3d and is more realistic.

Target: This parameter dictates whether the target is present or not during the Optic flow display. We have two options to choose from- Present and Not Present.

Target Present: This means that during the optic flow display the red fixation line at the center of the screen (also called as target) is present. This makes it easier for the observer to judge if the FOE was to the left or to the right of this center fixation since the target is always present during the visual display.

Target Not Present: This means that the red fixation line at the center of the screen is not displayed as long as the visual pattern appears on the screen. The duration of the visual pattern is based on the number of frames selected. Only before and after the end of each trial the center fixation line appears and the observer has to judge if the displayed visual pattern's FOE was to the left or to the right of it. The intermittent occurrence of the target before and after the visual pattern display makes it difficult for the observer to judge whether the FOE was to the left or to the right of this center fixation.

Object type: It indicates the type of object flowing in the visual field. In the optic field, it could be either flow of dots or flow of spheres. The optic flow module has been optimized to test the subjects with dots rather than spheres.

14. Tests and results

The Six experiments, their objectives and results is given below-

14.1 Experiment 1 - Detection of Optic flow - Optic flow test

Generation of Optic Flow Stimuli - An Optic flow module has been developed which will serve as the basic foundation for some of the other tests. A set of random dots appear from a source called focus of expansion and flows outwards in a 3-dimensional field. There is a fixation red line at the center of the screen. The dots appear at random locations to the left or right of the red fixation. If the user keeps judging correctly, the focus of expansion of the dots moves closer to the fixation. The module has some added features. Stimuli may be presented with or without the fixation, with or without masks of arbitrary size and location, and responses may be obtained with or without feedback on correctness. Also noise can be added to these tests to make the task harder. In this experiment, the parameters such as the size and the number of dots, their lifetime,

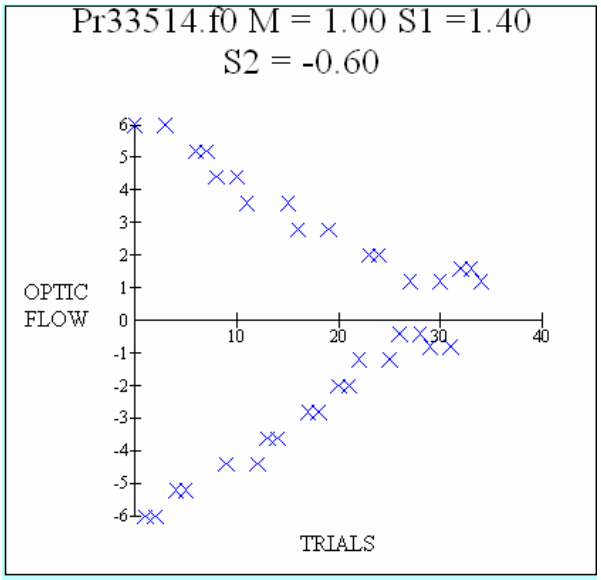
movement, etc can be increased or decreased across sessions to produce the desired stimuli.

TASK

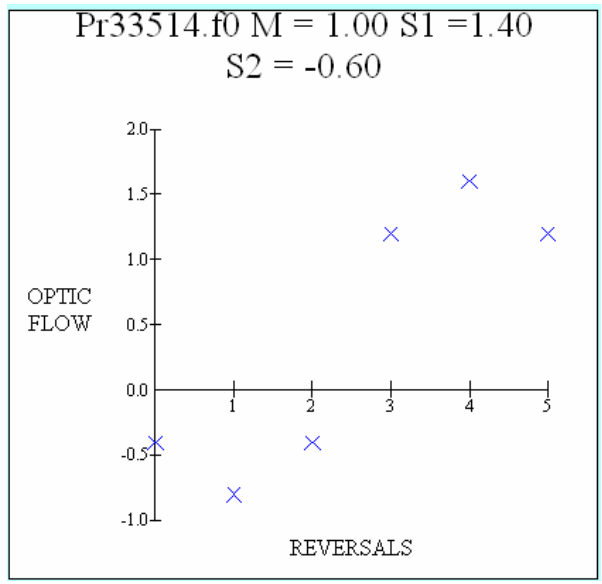
Thus in short, in the optic flow test, the observer views a series of two-alternative, spatial forced-choice trials. The task of the observer is to indicate the position of the source point (the point of origin of dots, also called the Focus of Expansion) with respect to a fixation i.e. the observer signals whether the flow of dots is originating from the left or right of the fixation line by clicking the left mouse button or the right mouse button respectively which is recorded in an output file stored in the folder "c:\edog\optic" for further analysis.

RESULTS & ANALYSIS OF THE OPTIC FLOW TEST

Figure 16 shows the results of an optic flow test conducted without feedback. The number of reversals was 2 per track. The tracking rule used was 2-right, 1 wrong rule. Figure 16(a) shows the response in terms of all trails. As we can see that the observer was as close as 0.4 units to the left of the fixation (equivalent to 8 pixels) and was as close as 1.2 units (equivalent to 24 pixels) to the right of the fixation. Figure 16(b) shows the reversals graphed that occurred at various offset values. The table below gives the reversals for both sides. Negative values indicate the left side of the center fixation while the positive values indicate the right side of the center fixation. The table also gives the mean for leftward and rightward deviations indicated as S1 and S2 in the table. The precision, PE and the bias, BI are also calculated and displayed. As can be seen, the mean for rightward deviations was 1.4 units (equivalent to 28 pixels) where as for the leftward deviations it was 0.6 units (12 pixels). The PE was 1.0 unit (20 pixels). The user was biased 0.8 units (16 pixels to the right of the fixation).



(a)



(b)

	Rev
0	-0.4
1	-0.8
2	-0.4
0	1.2
1	1.6
2	1.2
S1	1.4
S2	-.6
PE	1.
BI	.8

(c)

FIGURE 16: ANALYSIS OF OPTIC FLOW TEST

14.2 Experiment 2 - Detection of Curl or rotation in flow - Curl test

Detection of the direction of Curl or Rotation in optic flow is very useful in detecting shifts in vertical position or sway (refer **[9]**). For example; if one tilts to the left, there is clockwise (a circular motion to the right) rotation of the field.

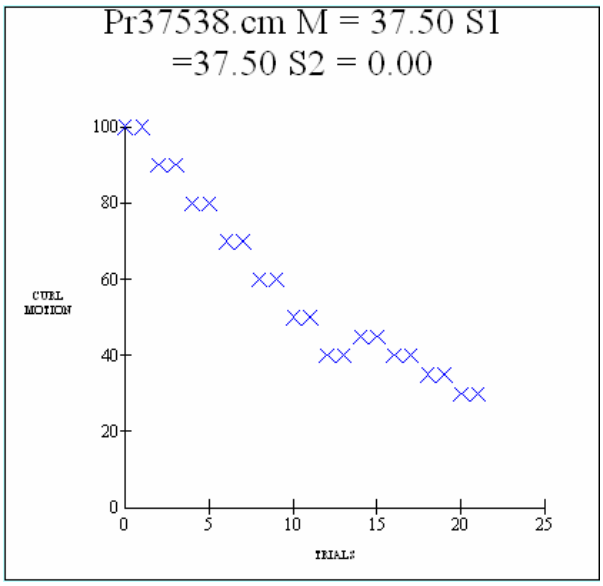
TASK

In case of curl or rotation of flow experiment, the observer views a cloud of dots which rotate either in clockwise or counter clockwise direction. The observer indicates whether

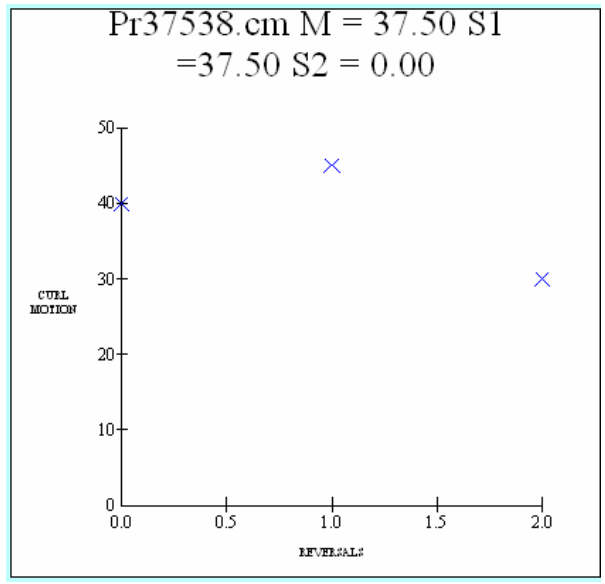
the flow of dots was counter-clockwise or clockwise by pressing the left or right mouse button respectively. Left click is registered for anticlockwise flow where as right click is registered as clockwise flow of dots. As the user keeps responding correctly, the test tends to be harder and noise comes into play to confuse the user. The number of dots moving randomly varies and tends to decrease if the observer is not able to judge properly. In this experiment, percentage coherence of dots starts off at the Offset value (usually 100%) and decreases by Offstep after 2 correct responses and thus the test becomes more and more difficult as the percentage coherence decreases. In this experiment, Offset means the percentage of coherence. The parameters such as the number of dots, size of dots, their lifetime and movement are variable and can be increased or decreased to produce the desired visual pattern.

RESULTS & ANALYSIS OF THE CURL OR ROTATIONAL FLOW TEST

Figure 17 shows the results of a curl or rotational flow test conducted with feedback. This test is usually conducted for a single staircase as there are no leftward and rightward deviations and hence single stair case makes sense. Also, the test has been modified to yield a single staircase even without feedback. The number of reversals was 2. The tracking rule used was 2-right, 1-wrong rule. Figure 17(a) shows the response in terms of all trails. From this figure, we can see that initially the flow of dots was 100% coherent. The observer went as low as 30% coherence. Figure 17(b) shows the reversals graphed that occurred at various offset values (%coherent values). The table below gives the reversals. It shows that the first reversal took place at 40% coherence. This can be verified from the first figure. This is usually ignored. The next reversals took place at 45% and 30% coherence. The mean of these two values is 37.5% coherence.



(a)



(b)

	Rev
0	40
1	45
2	30
M	37.5

(c)

FIGURE 17: ANALYSIS OF CURL OR ROTATIONAL FLOW TEST

14.3 Experiment 3 - Detection of motion parallax in laminar flow- Laminar test

One means of determining relative depth of two objects or planes is motion parallax, i.e. the fact that objects or planes in front of the point or plane of fixation appear to move faster while planes or objects behind fixation appear to move more slowly.

TASK

The basic paradigm for the Laminar Motion test is to have four frames with two sets of randomly placed dots. One set of dots moves to the left and the other moves to the right.

The speed of dots is faster in one direction. The task of the observer is to indicate which frame of dots is moving faster by clicking the left mouse button if the dots moving to the left (i.e. from right to left) are faster (or) right mouse button if the dots moving to the right are faster.

Parameters such as the number of dots, size of dots, lifetime, constant and variable speed can be changed across sessions to produce desired visual effects. In this experiment, there are two speeds-constant and variable. Some dots move at constant speed while some move at a variable speed. The variable speed tries to approach the constant speed as the observer keeps judging correctly and makes the test more difficult.

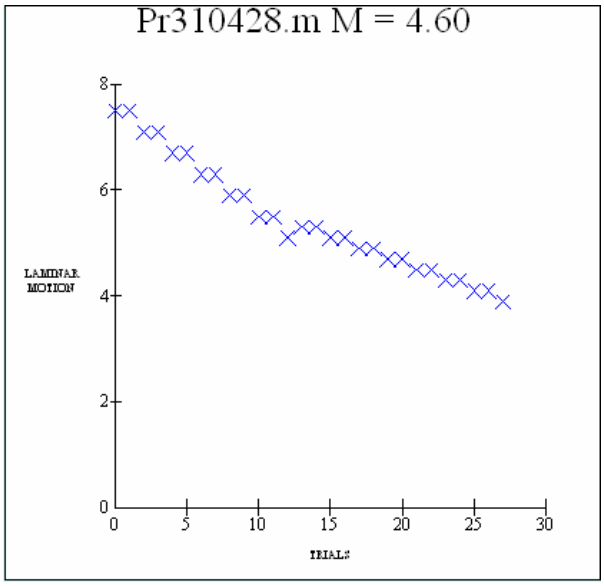
RESULTS & ANALYSIS OF THE LAMINAR FLOW TEST

Figure 18 shows the results of a Laminar flow test conducted with feedback. This test is usually conducted with feedback as there are no leftward and rightward deviations and hence single stair case makes sense. The experiment has been modified to yield single stair case even without feedback and hence in either case (with/without feedback), the experiment gives single staircase only. The number of reversals was 2. The tracking rule used was 2-right, 1 wrong rule. Figure 18(a) shows the response in terms of all trails. The value for Constant speed was 10 units per frame while for the variable speed it was 2.5 units per frame. The Offset step size was 0.2 units per frame. Figure 18(a) plots the difference between the Constant Speed and Variable Speed on Y axis against the number of trials on the X axis. Figure 18(b) gives the reversals graphed on X axis against the differences in speed on the Y axis. From the first figure we can see that initially (Units are units per frame)

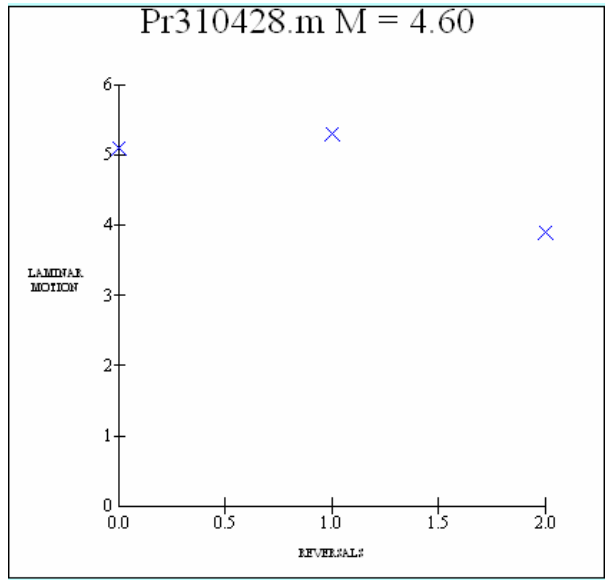
Constant Speed = 10; Variable Speed = 2.5 and the Offstep = 0.2.

So from the figure, we can observe that initially for the first trial, the difference in speeds was 7.5 and then after two consecutive responses, the difference in speeds was 7.1. This is because till the observer commits a mistake, the step size is doubled. So after another two consecutive correct responses, the difference in speeds is 6.7. The observer made his first mistake when the difference in speeds was 5.1. The observer was successfully able to differentiate the speed till the difference reached 3.9. The table shows the reversals that occurred at different Speed difference values. The mean of the difference in speeds which

the user was able to clearly differentiate was 4.6.



(a)



(b)

	Rev
0	5.1
1	5.3
2	3.9
M	4.6

(c)

FIGURE 18: ANALYSIS OF LAMINAR FLOW TEST

14.4 Experiment 4 - Effects of adding coherent, laminar Motion to optic flow

Duffy and Wurtz (refer **[8])** observed an illusion in heading judgements. If one masked radial flow with a second laminar flow field, the perceived FOE shifted in the direction of laminar (left or right) flow. Others have confirmed the illusion and suggested a variety of mechanisms to account for the effect, including motion capture and the properties of populations of neural cells in the primate brain.

TASK

In this experiment, the radial flow patterns are exactly the same as in optic flow (first experiment), but same or different number of dots moving either to the left or to the right

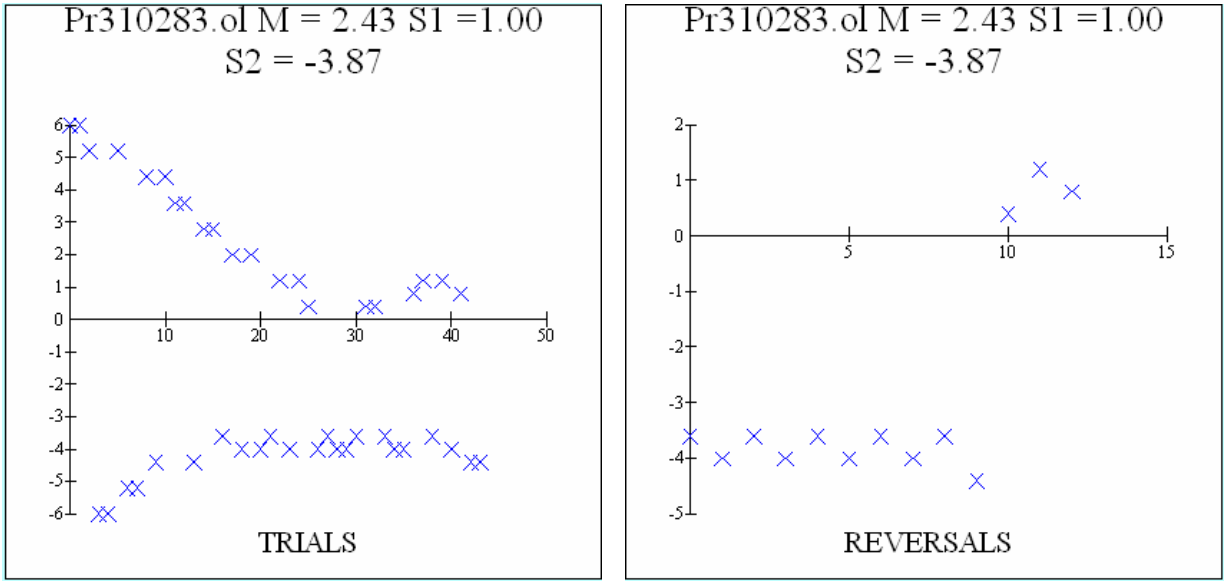
can be added. The constant error and the precision of judgements will be determined separately for the leftward and rightward laminar flow. The task of the observer is to indicate if the FOE is to the left or right of the fixation, something similar to the optic flow tests. Because of the presence of the laminar flow, the FOE appears to shift in the direction of the flow.

In this test, parameters such as the number of radial and laminar dots, speed of laminar flow are variable and can be changed across sessions to produce varying visual effects. The direction of the laminar flow can be changed to make the dots flow either to the left or to the right. Parameters such as size of the dots, lifetime of the dots and point movement are also variable and can be increased or decreased between sessions to produce the desired stimuli. The results are written in an output file stored in "c:\edog\optolaminar" folder for further analysis.

RESULTS & ANALYSIS OF THE OPTOLAMINAR FLOW TEST

Figure 19 shows the results of an optolaminar flow test conducted without feedback. The number of reversals was 2 per track. The tracking rule used was 2-right, 1 wrong rule. The number of Optic points was 75 and the number of laminar points was 25. The speed of the laminar dots was 10 units per frame. The direction of flow of laminar dots was from the left to the right of the screen. The experiment was conducted without the center fixation target during the visual pattern display. Figure 19(a) shows the response in terms of all trails. The positive values or the upper part of the graph indicates the right of the fixation while the negative values or lower part of the graph indicates the left side of the fixation. As we can see that the observer was as close as 3.6 units to the left of the fixation (equivalent to 72 pixels) and was as close as 0.4 units (equivalent to 8 pixels) to the right of the fixation. This was because the flow of laminar dots was from the left to the right of the screen. This provided an illusion to the observer that the FOE shifted a bit to the right side. That's the reason the observer did not perform well when the FOE was to the left of fixation. Figure 19(b) shows the reversals graphed that occurred at various offset values. The table below gives the reversals for both sides. The table also gives the mean for leftward and rightward deviations indicated as S1 and S2 in the table. The precision, PE and the bias, BI are also calculated and displayed. As can be seen, the mean

for rightward deviations was 1.0 unit (equivalent to 20 pixels) where as for the leftward deviations it was 3.87 units (approx 78 pixels). The PE was 2.43 units (49 pixels). The bias was 2.87 units (approx 58 pixels) to the left of the fixation. Note that the negative values indicate left side of the fixation.



(a) (b)

	Rev
0	-3.6
1	-4
2	-3.6
3	-4
4	-3.6
5	-4
6	-3.6
7	-4
8	-3.6
9	-4.4
0	0.4
1	1.2
2	0.8
S1	1.
S2	-3.87
PE	2.43
BI	-2.87

(c)

FIGURE 19: ANALYSIS OF OPTOLAMINAR TEST

14.5 Experiment 5 - Effects of adding speed noise to the Optic flow display

Adding variability to the speed of radial flow patterns appears to have minimal effect, if any in young normal subjects. In this experiment, the variability in speeds is obtained by changing the standard deviation of the speed parameter of dots. The mean speed of the dots is maintained constant because of the limitations on the range of speeds that can be obtained.

The speed of each dot is different and depends on the shape of the Gaussian function which is a bell shaped curve. The shape of this Gaussian function depends on two parameters - standard deviation and scale, and hence these parameters decide variability in the speed of the dots. The parameters such as the number of dots, their lifetime, movement, size, offset, standard deviation and the scaling factor are accepted as the input from the user and optic flow patterns with varying speeds of each dot are generated based on these input values.

For example, assume the mean speed is 6, the standard deviation is 3 and the scaling factor is 1 would mean that nearly 95% of the dots will have speeds between 4 and 8. Similarly, for a mean speed of 6, if the standard deviation is 3 and the scaling factor is 2 would mean that nearly 95% of the dots will have speeds between 2 and 10 and hence we get more variability in speeds. The user has to choose these parameter values sensibly because speeds less than 1 and greater than 10 have no meaning as they are either too slow or too fast. Also the Gaussian curve can be clipped to obtain limited speeds within a desired range.

The test can be conducted with various values of scale and standard deviation to obtain optic flow patterns with varying speeds. For the No noise or the basic optic flow test, set the scale parameter to zero. This would yield a visual pattern flow with constant speed i.e. the basic optic flow test.

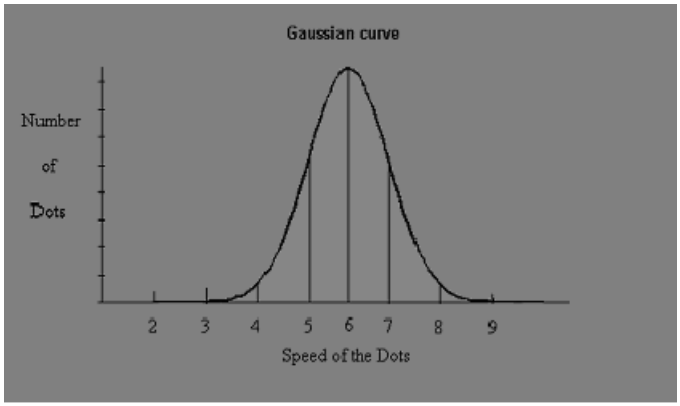


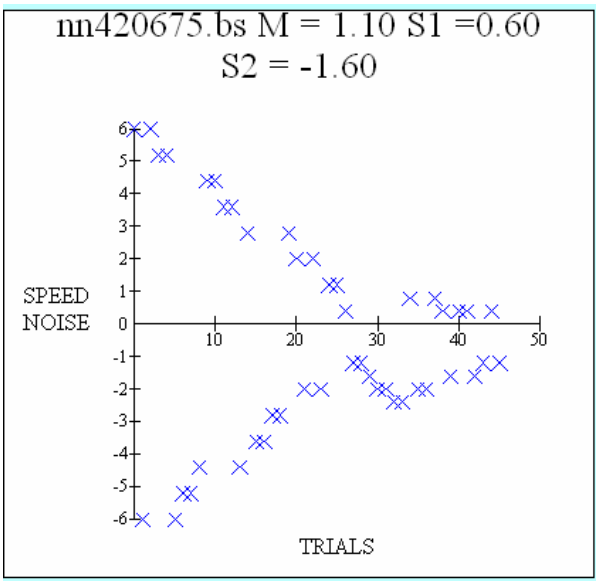
FIGURE 20: GAUSSIAN CURVE WITH MEAN = 6, SD = 3 & SCALE = 1

TASK

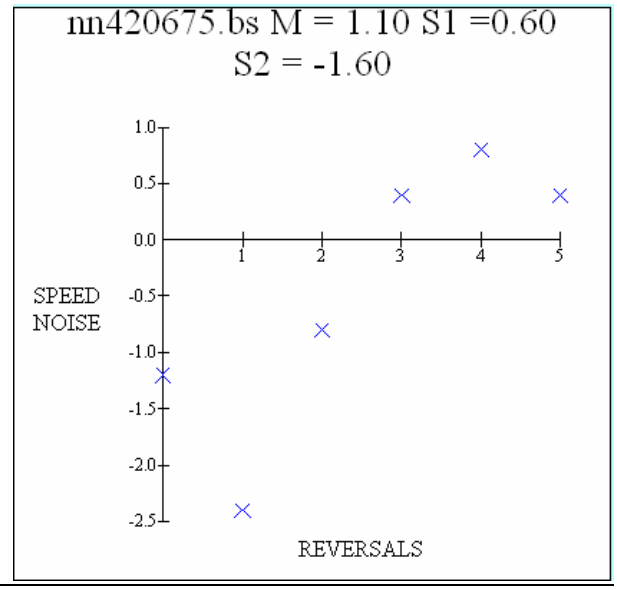
The task of the observer in this test is similar to the optic flow test i.e. the observer has to indicate if the FOE is to the left or to the right of the fixation by clicking left or right mouse button. The results are recorded in "c:\edog\speed" folder for further analysis.

RESULTS & ANALYSIS OF THE SPEED NOISE TEST

Figure 21 shows the results of a Speed Noise test conducted without feedback. The number of reversals was 2 per track. The tracking rule used was 2-right, 1-wrong rule. Figure 21(a) shows the response in terms of all trails. As we can see that the observer was as close as 1.2 units to the left of the fixation (equivalent to 24 pixels) and was as close as 0.4 units (equivalent to 8 pixels) to the right of the fixation. Figure 21(b) shows the reversals graphed that occurred at various offset values. The table below gives the reversals for both sides. Negative values indicate left side of the fixation while the positive values are for right side. The table also gives the mean for leftward and rightward deviations indicated as S1 and S2 in the table. The precision, PE and the bias, BI are also calculated and displayed. As can be seen, the mean for rightward deviations was 0.6 units (equivalent to 12 pixels) where as for the leftward deviations it was 1.6 units (32 pixels). The PE was 1.1 units (22 pixels). The bias was 1.0 unit (20 pixels) to the left of the fixation. As expected, adding speed noise to the optic flow seems to have minimal affect, if any, in judging the location of the Focus of Expansion (FOE).



(a)



(b)

	Rev
0	-1.2
1	-2.4
2	-0.8
0	0.4
1	0.8
2	0.4
S1	.6
S2	-1.6
PE	1.1
BI	-1.

(c)

FIGURE 21: ANALYSIS OF SPEED NOISE TEST

14.6 Experiment 6 - Effects of adding directional noise to Optic flow

Adding variability to the direction of the dots in radial flow patterns decreases the precision of judgements of heading in young normal subjects. This effect may be greater in case of patients with low vision and other visual defects. Noise is added by varying the standard deviation of the direction of motion of radial flow patterns.

The variability in direction is obtained by varying the standard deviation of the Gaussian function. The number and randomness in the direction of dots increase as the value of the standard deviation is increased. The shape of this Gaussian function depends on two

parameters - standard deviation (scale) and SD unit, and hence these parameters decide variability in the directional flow of dots. The parameters such as the number of dots, their lifetime, movement, size, offset, standard deviation and the scaling factor are accepted as the input from the user and the desired optic flow patterns are generated based on these input values.

The test can be conducted with various values of scale and standard deviation to obtain optic flow patterns with varying directional flow. For the No noise or the basic optic flow test, set the scale (standard deviation) parameter to zero. Increasing the scale (standard deviation) makes the test more difficult as the number of dots flowing randomly and their randomness tends to increase. The basic idea is to conduct the test with varying standard deviations and analyze the users' response to these tests.

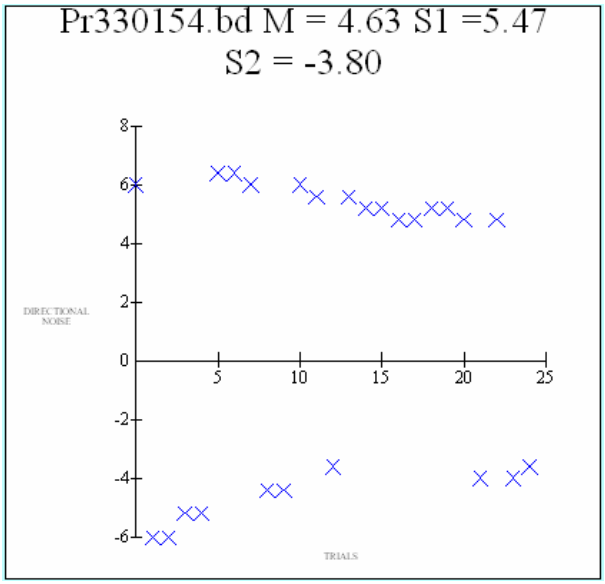
TASK

The task of the observer in this test is similar to the optic flow test i.e. the observer has to indicate if the FOE is to the left or to the right of the fixation by clicking left or right mouse button. The results are recorded in "c:\edog\direction" folder for further analysis.

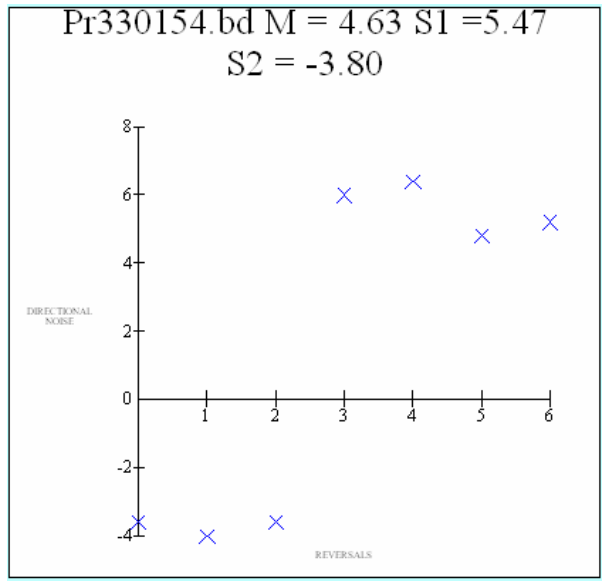
RESULTS & ANALYSIS OF THE DIRECTIONAL NOISE TEST

Figure 22 shows the results of a directional noise test conducted without feedback. The number of reversals was 2 per track. The standard deviation (scale) was 2.0 and the SD unit was 3.0. The tracking rule used was 2-right, 1 wrong rule. Figure 22(a) shows the response in terms of all trails. As we can see that the observer was as close as 3.6 units to the left of the fixation (equivalent to 72 pixels) and was as close as 4.8 units (equivalent to 96 pixels) to the right of the fixation. Figure 22(b) shows the reversals graphed that occurred at various offset values. The table below gives the reversals for both sides. Negative values indicate left side of the fixation while the positive values are for the right side. The table also gives the mean for leftward and rightward deviations indicated as S1 and S2 in the table. The precision, PE and the bias, BI are also calculated and displayed. As can be seen, the mean for rightward deviations was 5.47 units (equivalent to 110 pixels) where as for the leftward deviations it was 3.8 units (76 pixels). The PE was 4.63 units (93 pixels). The user was biased 1.67 units (34 pixels to the right of the fixation).

Note that negative values indicate left side of the fixation. As expected, it can be seen from the results that the user had a difficult time responding correctly to the test. This proves that adding directional noise to the optic flow test reduces the ability of the observer to detect the FOE with the same accuracy and precision as he would have done in the normal optic flow test.



(a)



(b)

	Rev
0	-3.6
1	-4
2	-3.6
0	6
1	6.4
2	4.8
3	5.2
S1	5.47
S2	-3.8
PE	4.63
BI	1.67

(c)

FIGURE 22: ANALYSIS OF DIRECTIONAL NOISE TEST (SDU =3 & Scale =2)

15. Limitations of the application & improvements

The application has been successfully tested and implemented on computers with different processing power, memory and screen sizes. The application has been successful on these computers, but certain improvements can be made. The following improvements can be made –

1. The frame rate can be fixed to remain the same on computers with different processing abilities i.e. the display of visual patterns can be made periodic irrespective of the processing power of a computer. This would require that some kind of a timer function be used to control the timing and period of the visual display. This would eliminate the need to measure the frame rate of a computer.
2. In case of experiments such as Optic flow test, Optolaminar test, Speed and Directional test, the observer has to complete the given number of reversals on both tracks/sides. Sometimes this would make the test never ending as the observer may complete reversals on one track/side and not complete any reversal on other side. A simple solution to this problem is to quit the experiment after a certain number of trials on that particular track/side.
3. The application needs rigorous calibrations and measurements such as measuring the frame rate, the speed of points etc. Improvements can be made to reduce the amount of calculations and calibration.
4. Few more thresholding strategies could be developed such as the Quest, Pest etc.
5. The number of trails is presently restricted to 300. This can be increased to accommodate atypical cases.

16. Challenges encountered

There were several programming issues that had to be solved because of the constraint on the way the optic flow patterns had to be generated for example the dots had to be reproduced again if they moved out of the viewing frustum or if their lifetime had expired, etc. Also, different computers have different timing issues and obtaining consistent performance on these platforms was difficult. Also, the initial programs were written in C language. It was decided to start using OpenGL for these programs as the 3-dimensional nature of the optic flow was better represented and easily implemented using

OpenGL. Identifying the required necessary dynamic link library files, parameter files, default files, etc for developing an installation version of the application package was challenging as well. The tests had been coded using VC++ and their executable files were generated. If any changes had to be made to the test, all the files had to be recompiled and the executable files generated again and included in the application package. This was a demanding and a time consuming task.

17. Implementation and future work

All the above tests will be used to determine whether patients with visual impairment can respond to optic flow. The following are the objectives-

1. To determine whether people can respond to the stimulus.
2. To determine the response difference between people with visual impairment and those without visual impairment of the same age, if there is any.
3. Finally to determine if subjects with different visual impairment respond distinctively to optic flow detection.

In this problem report, the results of conducting several optic flow tests on subjects without any serious visual problems have been documented. Experimental results suggest that the variation in response was very less among the group of people without much serious visual impairment. People with different kinds of low vision problems such as age-related macular degeneration, glaucoma, or diabetic retinopathy may respond distinctively to these optic flow stimuli. Further research, data collection and analysis needs to be done on the above category of patients to determine the amount and the type of variation in response.

Assuming low-vision patients can respond to optic flow information, and subjects respond distinctively, then more realistic virtual-reality tests can be developed. These tests will be helpful in determining whether or not differences in performance are related to the ability of patients to acquire skills in mobility. Additionally, the virtual environments created may serve as useful training situations for patients with low-vision. A new study on effects of prism orientation on heading judgments in optic flow displays is also being conducted as a part of future research.

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[9] Grant Proposal.[1]

[1] Grant Number EY014841 to J. Vernon Odom funded by National Eye Institute (NEI).

APPENDIX

- J. Vernon Odom, Prasad Ghude, Frances L. VanScoy, Arun Ross, Homer Humble. **"Human Response to Different Adaptive Optic Flow Stimuli"**, *Proc. of the 11th International Conference on Virtual Systems and Multimedia (VSMM 2005)*, (Ghent, Belgium), pp. 257-266, Oct'05.

- P. Ghude, F. VanScoy, J.V. Odom, V. Baker, R. Hussmann, S. Vemury, J. Tong, J Schraff. **"Higher Order Visual Perception: An Application for Evaluation of Low Vision"**, *Proc. of the 10th International Conference on Virtual Systems and Multimedia (VSMM 2004)*, (Ogaki city, Japan), pp. 406-415, Nov'04.

- J. Vernon Odom, Prasad Ghude, Homer Humble. **"Effect of Prism Orientation on Heading Detection in Optic Flow"**, *Journal of Modern Optics, Taylor & Francis*. *Accepted – Under Review***.**

Human Response to Different Adaptive Optic Flow Stimuli

J. Vernon Odom
WVU Eye Institute,
Morgantown,
WV 26506-6109, U.S.A.
odomj@rcbhsc.wvu.edu

Prasad Ghude [2]
Lane Dept. of CSEE,
West Virginia University,
Morgantown,
WV 26506-6109, U.S.A.
prasadghude@gmail.com

Arun Ross
Lane Dept. of CSEE,
West Virginia University,
Morgantown,
WV 26506-6109, U.S.A.
ross@csee.wvu.edu

Homer Humble
Dept. of Ophthalmology,
WVU Eye Institute,
Morgantown,
WV 26506-6109, U.S.A.
humbleh@rcbhsc.wvu.edu

Frances L. VanScoy
Lane Dept. of CSEE,
West Virginia University,
Morgantown,
WV 26506-6109, U.S.A.
vanscoy@cs.wvu.edu

Abstract. The term "Optic flow" refers to the change in visual input as a person moves through an environment. It is the apparent visual motion we experience as we move through an environment and it is a common visual phenomena that we experience everyday. Optic flow can be characterized by several components, including radial flow either inward or outward, laminar flow to the left or to the right, rotation or curl which is clockwise or counterclockwise motion, and deformation or change in shape.

Significant research has been performed to investigate how humans, animals and insects use optic flow to navigate through the world. However, not much research has been conducted to study the impact of eye diseases, age or environmental conditions on optic flow detection. In our efforts, we have designed six different types of simulated optic flow stimuli and these have been integrated to a graphical user interface in order to understand and analyze the general response of humans to these stimuli. The parameters of our model such as the number of dots, their lifetime, speed, etc. may be varied through the graphical user interface to produce desired visual patterns on the screen. These optic flow modules (corresponding to each stimulus) have been generated using OpenGL to better represent their 3-dimensional nature. The tests are adaptive in nature i.e. their level of difficulty is based on subject's response. The subject indicates the position of the FOE (Focus of Expansion) by clicking the left or the right mouse button. The basic idea is to determine and analyze the response of humans with different visual impairments to various adaptive optic flow stimuli.

1. Introduction

Optic flow is the change in visual input as a person moves through an environment. It has been characterized by several components, including radial flow either inward or outward, rotational flow of dots in either clockwise or counterclockwise direction, laminar flow of dots to the left or right, and deformation or change in shape due to the addition of directional noise or speed noise. The pioneer work on detection of optic flow by Gibson **([1], [2], [3])** has been identified as a major determinant of people's ability to successfully navigate in their environment. In an optic flow field, there is a stationary point from which all of the changes flow. The stationary *Focus of Expansion* (FOE) is the point toward which

[2] Corresponding Author

the person is heading. Thus, Gibson's major insight was that detecting the FOE was sufficient to determine a person's heading.

The study presented in the paper is novel because it is the first effort in its kind in presenting a group of six tasks that are designed to understand the ability of low vision patients to process optic flow information. The bias and precision of FOE judgments are also calculated. Understanding the optic flow processing ability of low vision patients is of major impact because it has direct and immediate implications on the ability of low vision patients to navigate in their environment. Our long-range objective is to examine the impact of reduced vision on higher order perceptual abilities and the relationship between differences in perceptual abilities on the performance of simulated and real tasks of everyday living. Improved understanding of the role of vision in assisting the partially sighted to find their way and perform their activities of daily living will improve our ability to provide them with better rehabilitation services designed to fit their current abilities and environment.

2. Method

This paper presents an innovative approach to determining the response of humans with various kinds of visual impairments to different optic flow stimuli wherein six different kinds of adaptive optic flow stimuli have been generated. These stimuli have been integrated to a Graphical User Interface for analyzing the responses, in general of humans to these varying stimuli. An optic flow module has been developed which determines subject's bias and precision for detecting optic flow. The basic method is similar to others in the literature **[4]**, but the module has several added features. Stimuli may be presented with or without a target fixation, with or without masks of arbitrary size and location, and responses may be obtained with or without feedback on correctness. The number of dots, their size, lifetime, speed, etc. can also be varied from the GUI to produce varying visual patterns. The application also permits the addition of directional noise, speed noise, rotational or laminar motion, optic flow with simultaneous laminar flow, etc. Two basic assumptions have been made -

5. Subjects are capable of responding to optic flow and its components.
6. Their performance will vary slightly based on the type of visual impairment.

2.1 Procedure for assessment of Optic Flow thresholds - Threshold determination

The subject looks at a video monitor. A sparse cloud of dots originating from a point (source) and moving outwards is presented on the screen. This source point, also called as the FOE (Focus of Expansion), can be located to the left or right of the center of the video monitor. Following stimulus presentation, a red fixation target appears at the center of the screen and the subject is asked to indicate whether the FOE was to the left or to the right of the target by pressing the left or the right button of a mouse respectively. In other tests such as the curl test, the person needs to identify the direction of rotation. In case of laminar flow test, the objective is to indicate which set of dots is flowing faster among the two sets. In optolaminar test, there will be a simultaneous laminar flow that will be added to the basic optic flow. The direction of the laminar flow could be left or right and the objective is to identify the location of the FOE with respect to the center fixation.

In all the above cases, using a dual, adaptive thresholding technique which employs a 2 down 1 up rule (defined in section 3.1), we gradually bring the FOE closer to the center of the screen. Two values are identified, one being the mean for the staircase detecting leftward deviations of the target (negative value) and one being the mean for the staircase detecting rightward deviations (positive value). The midpoint between these two is the

Point of Subjective Equality (PSE, Constant Error) and represents the person's bias in estimating the location of the FOE. One half of the distance between the two points estimates the Precision of the person's estimate of FOE location. Thus, measuring the bias and precision of FOE judgments provides a complete picture of the subjects' performance.

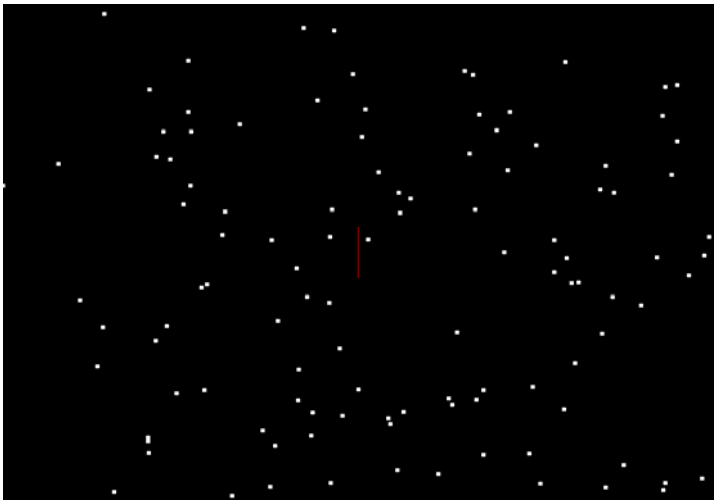


Figure 1. Sample Optic flow stimulus

3. Results and Analysis

The six experiments described below were conducted on several people. The response and trends in most cases were similar for a particular experiment. The response of one of the subjects to six different kinds of optic flow stimuli is given below -

3.1 Experiment 1 - Detection of Optic Flow - Optic Flow test

Generation of Optic Flow Stimuli - An Optic flow module has been developed which will serve as the basic foundation for some of the other tests. A set of random dots appear from a source called Focus of Expansion and flow outwards in a 3-dimensional field. There is a fixation red line at the center of the screen. The dots appear at random locations to the left or right of the red fixation. After each stimulus presentation, the observer is asked to indicate whether the FOE was to the left or to the right of the center fixation. If the observer keeps judging correctly, the Focus of Expansion of the dots moves closer to the center fixation. Also, noise can be added to make the task harder.

In this experiment, the parameters such as the size of the dots, their number, lifetime, movement, etc. can be increased or decreased across sessions to produce the desired stimuli. The test starts off with the FOE at a certain Offset (a predefined user parameter) distance from the center fixation. Then, depending on the value of offset step size (also a user input); the FOE starts moving closer/farther to the center fixation. There are two tracking rules that can be used in the application. A tracking procedure determines the location and the number of times the FOE occurs at a particular Offset distance from the center. We mostly use the 2-down/1-up rule (also called 2-Correct/1-Incorrect rule).This rule increases difficulty by one step after two consecutive correct responses and decreases difficulty by one step after one incorrect response. The test is adaptive in nature and once the given number of reversals is completed, the test quits and the control returns to the GUI.

TASK

Thus, in the optic flow test, the observer views a series of two-alternative, spatial forced-choice trials. The task of the observer is to indicate the position of the FOE with respect to a

fixation i.e. the observer indicates whether the flow of dots is originating from the left or right of the fixation line by clicking the left mouse button or the right mouse button respectively, the details of which are recorded in an output file for further analysis.

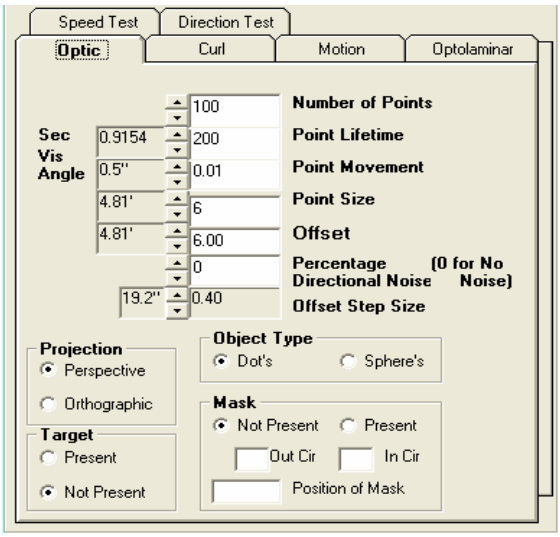
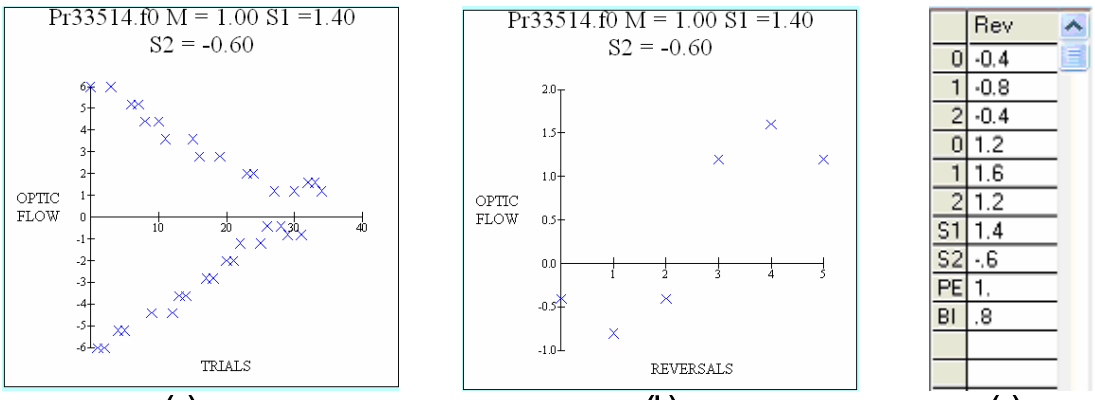


Figure 2. Optic flow test Interface indicating the test specific parameters

3.1.1 Results and Analysis of the Optic flow test

Figure 3 shows the results of an optic flow test conducted without feedback on correctness. The number of reversals was 2 per track. The tracking rule used was 2-right, 1-wrong rule (also called 2 DOWN 1 UP rule). Figure 3(a) shows the response in terms of all trails. It's clear from the figure that the observer was as close as 0.4 units (equivalent to 8 pixels) to the left of the center fixation and was as close as 1.2 units (equivalent to 24 pixels) to the right of the center fixation. Figure 3(b) shows the reversals graphed that occurred at various offset values. The table in figure 3(c) summarizes the reversals for both sides and also gives the mean for leftward and rightward deviations indicated by S1 and S2. The precision, PE and the bias, BI (defined in section 2.1) are also calculated and displayed. As can be seen, the mean for the rightward deviations was 1.4 units (equivalent to 28 pixels from the center fixation) where as for the leftward deviations it was 0.6 units (12 pixels). The PE was 1.0 unit (20 pixels). The observer's bias was 0.8 units (16 pixels to the right of the fixation). Note that 1 unit = 20 pixels and that negative values (lower part of graph) indicate the left side of the center fixation while the positive values (upper part of graph) indicate the right side of the center fixation.



(a) (b) (c)

Figure 3. Analysis of Optic flow test

3.2 Experiment 2 - Effects of adding Speed Noise to Optic flow

Adding variability to the speed of radial flow patterns appears to have minimal effect, if any in young normal subjects **[8]**. In this experiment, the variability in speeds is obtained by changing the standard deviation of the speed parameter of dots. The mean speed of the dots is maintained constant because of the limitations on the range of speeds that can be obtained.

The speed of each dot is different and depends on the shape of the Gaussian function which is a bell shaped curve. The shape of this Gaussian function depends on two parameters - standard deviation and scale, and hence these parameters decide variability in the speed of the dots. The parameters such as the number of dots, their lifetime, movement, size, offset, standard deviation and the scaling factor are accepted as the input from the user and optic flow patterns with varying speeds for each dot are generated based on these input values.

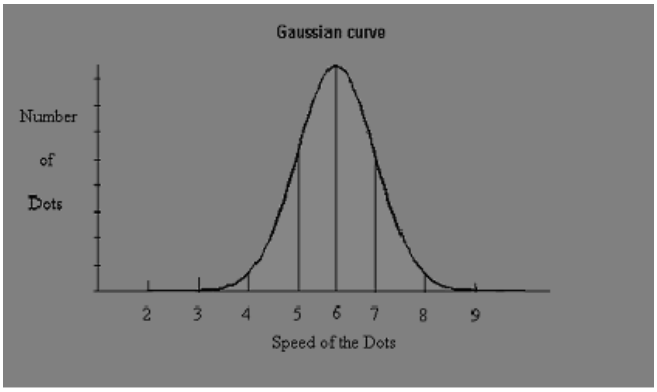


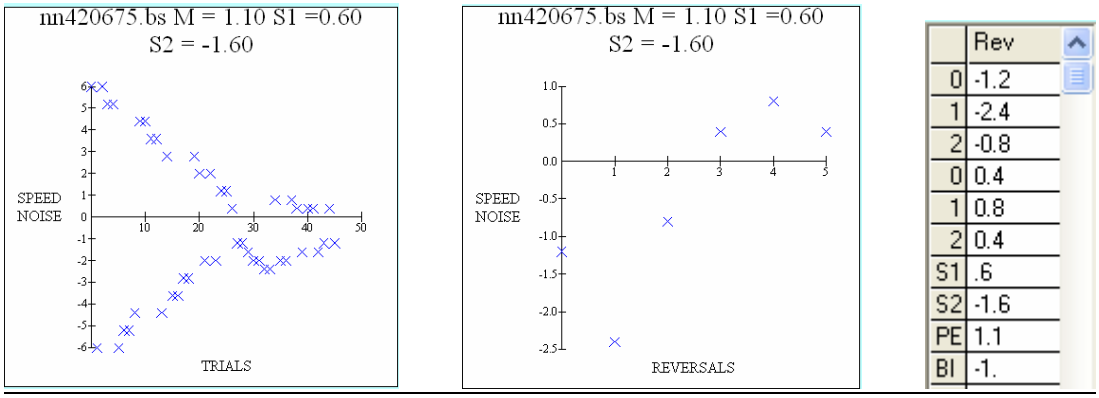
Figure 4. Gaussian curve with mean = 6, SD = 3 & scale = 1

TASK

The task of the observer in this test is similar to the optic flow test i.e. the observer has to indicate if the FOE is to the left or to the right of the fixation by clicking left or right mouse button.

3.2.1 Results and Analysis of the Speed Noise test

Figure 5 shows the results of the Speed Noise test conducted without feedback. The number of reversals was 2 per track. Figure 5(a) shows the response in terms of all trials. As we can see that the observer was as close as 1.2 units to the left of the fixation (equivalent to 24 pixels) and was as close as 0.4 units (equivalent to 8 pixels) to the right of the fixation. Figure 5(b) shows the reversals graphed that occurred at various offset values. The table in figure 5(c) gives the reversals for both sides. Negative values indicate left side of the fixation while the positive values are for right side of the fixation. The table also gives the mean for leftward and rightward deviations indicated as S1 and S2 in the table. The precision, PE and the bias, BI are also calculated and displayed. As can be seen, the mean for rightward deviations was 0.6 units (equivalent to 12 pixels) where as for the leftward deviations it was 1.6 units (32 pixels). The PE was 1.1 units (22 pixels). The bias was 1.0 unit (20 pixels) to the left of the fixation. As expected, adding speed noise to the optic flow seems to have minimal affect, if any, in judging the location of the Focus of Expansion.



(a) (b) (c)

Figure 5. Analysis of Speed Noise test

3.3 Experiment 3 - Effects of adding Directional noise to optic flow

Adding variability to the direction of the dots in radial flow patterns decreases the precision of judgements of heading in young normal subjects **[8]**. This effect may be greater in case of patients with low vision and other visual defects. Noise is added by varying the standard deviation of the direction of motion of radial flow patterns.

The variability in directional flow is obtained by changing the standard deviation and the scaling factor of the Gaussian function. The number and randomness in the direction of dots increase as the values of the standard deviation and scale are increased. The parameters such as the number of dots, their lifetime, etc are accepted as input values from the GUI and desired optic flow patterns are generated based on these input values.

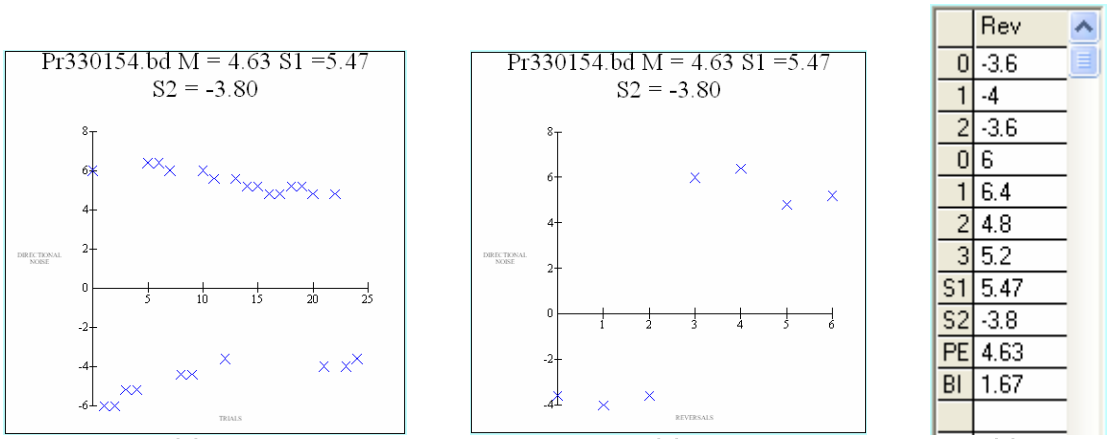
The test can be conducted with various values of scale and standard deviation to obtain optic flow patterns with varying directional flow. The basic idea is to conduct the test with varying standard deviations and analyze the observer's response to these tests.

TASK

The task of the observer is similar to the optic flow test i.e. the observer has to indicate if the FOE is to the left or right of the fixation by clicking left or right mouse button.

3.3.1 Results and Analysis of the Directional Noise test

Figure 6 shows the results of a directional noise test conducted without feedback. The number of reversals was 2 per track. The standard deviation was 3.0 and the scaling factor was 2.0. The first figure shows the response in terms of all trails. As we can see that the observer was as close as 3.6 units to the left of the fixation (equivalent to 72 pixels) and was as close as 4.8 units (equivalent to 96 pixels) to the right of the fixation. The second figure shows the reversals graphed that occurred at various offset values. The table below gives the reversals for both sides. Negative values indicate left side of the fixation while the positive values are for the right side. The table also gives the mean for leftward and rightward deviations indicated as S1 and S2 in the table. The precision, PE and the bias, BI are also calculated and displayed. As can be seen, the mean for rightward deviations was 5.47 units (equivalent to 110 pixels) where as for the leftward deviations it was 3.8 units (76 pixels). The PE was 4.63 units (93 pixels). The observer's bias was 1.67 units (34 pixels to the right of the fixation). As expected, it can be seen from the results that the observer had a difficult time responding correctly to the test. This proves that adding directional noise to the optic flow test reduces the ability of the observer to detect the FOE with the same accuracy and precision as he would have done in case of the normal optic flow test.



(a) (b) (c)

Figure 6. Analysis of Directional noise test

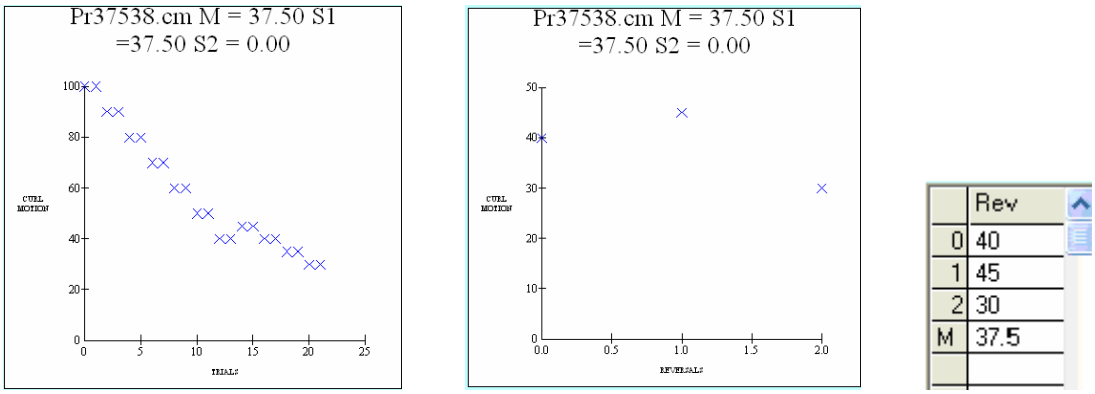
3.4 Experiment 4 - Detection of Curl or Rotation in Flow - Curl or Rotational Flow test

Detection of the direction of Curl or Rotation in optic flow is very useful in detecting shifts in vertical position or sway **[8]**. For example; if one tilts to the left, there is clockwise (a circular motion to the right) rotation of the field.

TASK

In case of curl or rotation of flow experiment, the observer views a cloud of dots which rotates either in clockwise or counter clockwise direction. The observer indicates whether the flow of dots was counter-clockwise or clockwise by pressing the left or right mouse button respectively. Left click is registered for anticlockwise flow where as right click is registered as clockwise flow of dots.

As the observer keeps responding correctly, the test tends to be harder and random noise comes into play to confuse the observer. The number of dots moving randomly varies and tends to decrease if the observer is not able to judge properly. In this experiment, percentage coherence of dots starts off at the Offset value (usually 100%) and decreases by offset step size (an input parameter) after every 2 consecutive correct responses and thus the test becomes more and more difficult as the percentage coherence of dots decreases. In this experiment, Offset indicates the percentage of coherence which varies based on observers response and the offset step size (input parameter). The parameters such as the number of dots, size of dots, their lifetime and movement are variable and can be increased or decreased to produce the desired visual pattern.



(a) (b) (c)

Figure 7. Analysis of Curl or rotational flow test

3.4.1 Results and Analysis of the Curl or Rotational Flow test

Figure 7 shows the results of curl or rotational flow test conducted with feedback on correctness. This test is usually conducted with a single staircase as there are no leftward and rightward deviations and hence a single stair case makes sense. The number of reversals was 2. Figure 7(a) shows the response in terms of all trails. From this figure, we can see that initially the flow of dots was 100% coherent. The observer could make out the direction of rotation till the coherence was as low as 30%. Figure 7(b) shows the reversals graphed that occurred at various offset values (% coherent values). The table in figure 7(c) gives the reversals. It shows that the first reversal took place at 40% coherence. This can be verified from the first figure. This is usually ignored. The next reversals took place at 45% and 30% coherence. The mean of these two values is 37.5% coherence as indicated in the table.

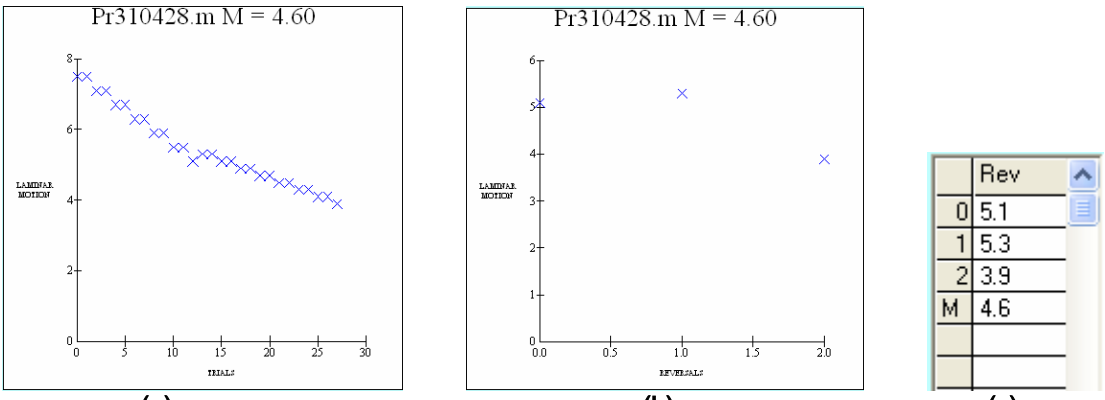
3.5 Experiment 5 - Detection of Motion Parallax in Laminar Flow- Laminar test

One means of determining relative depth of two objects or planes is motion parallax, i.e. the fact that objects or planes in front of the point or plane of fixation appear to move faster while planes or objects behind fixation appear to move more slowly **[8]**.

The basic paradigm for the Laminar Motion test is to have four frames with two sets of randomly placed dots. One set of dots moves to the left while the other moves to the right. The speed of dots is faster in one direction. Parameters such as the number of dots, size of dots, lifetime, constant and variable speed can be changed across sessions to produce desired visual effects. In this experiment, there are two speeds-constant and variable. Some dots move at constant speed while some move at a variable speed. The variable speed approaches the constant speed as the observer keeps judging correctly and hence makes the test more difficult.

TASK

The task of the observer is to indicate which frame of dots is moving faster by clicking the left mouse button if the dots moving to the left (i.e. from right to left) are faster (or) right mouse button if the dots moving to the right are faster.



(a) (b) (c)

Figure 8. Analysis of Laminar flow test

3.5.1 Results and Analysis of the Laminar Flow test

Figure 8 above shows the results of a Laminar flow test conducted with feedback. The first figure shows the response in terms of all trails. The value for Constant speed was 10 units per frame (where 1 unit = 0.5 pixels) while for the variable speed it was 2.5 units per frame

(where 1 unit = 0.5 pixels). The Offset step size was 0.2 units per frame. The first figure plots the difference between the Constant Speed and Variable Speed on Y axis against the number of trials on the X axis. The second figure gives the reversals graphed on X axis against the differences in speed on the Y axis. From the first figure we can see that initially (Units are units per frame where 1 unit = 0.5 pixels)
Constant Speed = 10; Variable Speed = 2.5 and the Offstep = 0.2.

So from the figure, we can observe that initially for the first trial, the difference in speeds was 7.5 and then after two consecutive responses, the difference in speeds was 7.1. This is because till the observer commits a mistake, the step size is doubled to quickly home onto the threshold value. So after another two consecutive correct responses, the difference in speeds is 6.7. The observer made his first mistake when the difference in speeds was 5.1. The observer was successfully able to differentiate the speed till the difference reached 3.9. The table shows the reversals that occurred at different Speed difference values. The mean of the difference in speeds which the user was able to clearly differentiate was 4.6.

3.6 Experiment 6 - Effects of adding Coherent, Laminar Motion (Optolaminar flow test)

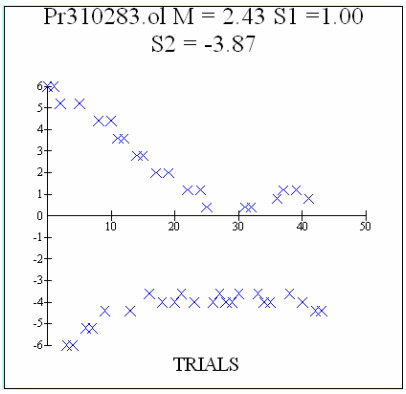
Duffy and Wurtz, **[5]** observed an illusion in heading judgements. If one masked radial flow with a second laminar flow field, the perceived FOE shifted in the direction of laminar (left or right) flow. Others have confirmed the illusion and suggested a variety of mechanisms to account for the effect, including motion capture **[6]** and the properties of populations of neural cells in the primate brain **[7]**. This illusion is thought to mimic errors in heading judgements made when the eyes are not fixating straight ahead.

TASK

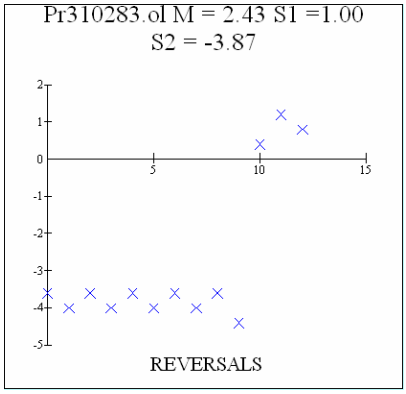
In this experiment, the radial flow patterns are exactly the same as in optic flow (first experiment), but same or different number of dots moving either to the left or to the right can be added. The task of the observer is to indicate if the FOE is to the left or right of the fixation, something similar to the optic flow test. The presence of the laminar flow shifts the perceived FOE in the direction of the laminar flow, i.e. the FOE appears to be shifted a bit in the direction of laminar flow. The direction of the laminar flow can be changed to make the dots flow either to the left or to the right. Parameters such as size of the dots, lifetime, point movement, etc can be varied between sessions to produce the desired stimuli.

3.6.1 Results and Analysis of the Optolaminar Flow test

Figure 9 shows the results of an optolaminar flow test conducted without feedback. The number of Optic points was 75 and the number of laminar points was 25. The speed of the laminar dots was 2 pixels per frame. The direction of flow of laminar dots was from the left to the right of the screen. Figure 9(a) shows the response in terms of all trails. As we can see that the observer was as close as only 3.6 units to the left of the fixation (equivalent to 72 pixels) while he was as close as 0.4 units (equivalent to 8 pixels) to the right of the fixation. This was because the flow of laminar dots was from the left to the right of the screen. This provided an illusion to the observer that the FOE shifted a bit to the right side. That’s the reason the observer did not perform well when the FOE was to the left of fixation. Figure 9(b) shows the reversals graphed that occurred at various offset values. As can be seen, the mean for rightward deviations was 1.0 unit (equivalent to 20 pixels) where as for the leftward deviations it was 3.87 units (approximately 78 pixels). The PE was 2.43 units (49 pixels). The observer’s bias was 2.87 units (approx 58 pixels) to the left of the fixation. This proves that the perceived FOE shifts in the direction of laminar flow.



(a)



(b)

	Rev
0	-3.6
1	-4
2	-3.6
3	-4
4	-3.6
5	-4
6	-3.6
7	-4
8	-3.6
9	-4.4
0	0.4
1	1.2
2	0.8
S1	1.
S2	-3.87
PE	2.43
BI	-2.87

(c)

Figure 9. Analysis of Optolaminar test

4. Conclusion

In this paper, we have presented the results of conducting several optic flow tests on people without any serious visual problems. Experimental results suggest that the variation in response was very less among the group of people without much serious visual impairment. People with different kinds of low vision problems such as age-related macular degeneration, glaucoma, or diabetic retinopathy may respond distinctively to these optic flow stimuli. Further research, data collection and analysis needs to be done on the above category of patients to determine the amount and the type of variation in response.

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[8] Grant Proposal [3]

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Higher Order Visual Perception: An Application for Evaluation of Low Vision

Prasad Ghude [4]
Lane Dept. of CSEE,
West Virginia University,
Morgantown,
WV 26506-6109, U.S.A.
prasadg@csee.wvu.edu

Frances L. VanScoy
Lane Dept. of CSEE,
West Virginia University,
Morgantown,
WV 26506-6109, U.S.A.
vanscoy@cs.wvu.edu

J. Vernon Odom
Dept. of Ophthalmology,
WVU Eye Institute,
Morgantown,
WV 26506-6109, U.S.A.
odomj@rcbhsc.wvu.edu

David V. Baker
Lane Dept. of CSEE,
West Virginia University,
Morgantown,
WV 26506-6109, U.S.A.
Vic.Baker@mail.wvu.edu

Ricky Hussmann
Lane Dept. of CSEE,
West Virginia University,
Morgantown,
WV 26506-6109, U.S.A.
rhussman@mix.wvu.edu

Srinivas Jaya Vemury
Lane Dept. of CSEE,
West Virginia University,
Morgantown,
WV 26506-6109, U.S.A.
srinivasjaya@hotmail.com

James Tong
Computer Science Dept.,
Carnegie Mellon University,
5000 Forbes Ave, Pittsburgh,
PA 15213-3891, U.S.A
jetong@cmu.edu

Jeanne Schraf
Lane Dept. of CSEE,
West Virginia University,
Morgantown,
WV 26506-6109, U.S.A.
jschraf@mix.wvu.edu

Abstract. Low vision is a major health problem, especially among the elderly; their reduced vision impairs their ability to navigate, impairs their ability to perform activities of daily living independently, and places them at greater risk for accidents and deaths. This paper presents an innovative approach for understanding the optic flow processing ability of low vision patients wherein an application has been developed using Visual Basic and a series of tests have been written using OpenGL which are being integrated to the GUI for analyzing patients with different kinds of visual problems such as age-related macular degeneration, glaucoma, or diabetic retinopathy.

A Graphical User Interface (GUI) has been developed which at the backend calls several low vision tests written in OpenGL. These Optic flow tests have been written using OpenGL for analyzing the visual abilities of patients with low vision and the role these visual abilities play in their daily lives. These tests are adaptive in nature i.e. they tend to be difficult/easier based on the user's response and are written in OpenGL since the visual patterns have to be presented in a 3-dimensional environment. The objective of developing this application is to examine the impact of reduced vision on higher order visual perceptual abilities and the relationship of differences in perceptual abilities on the performance of simulated and real tasks of everyday living.

1. Optic Flow and Mobility

Optic flow is the change in visual input as a person moves through the environment. It has been characterized by several components, including radial flow either inward or outward, laminar flow to the left or right, rotation or curl which is clockwise or counterclockwise

[4] Corresponding Author

motion, and deformation or change in shape. In an optic flow field, there is a stationary point from which all of the changes flow. The stationary *Focus of Expansion* (FOE) is the point toward which the person is heading. The pioneer work on detection of optic flow by Gibson (**[1], [2], [3]**) has been identified as a major determinant of people's ability to successfully navigate in their environment. Thus, Gibson's major insight was that detecting the FOE was sufficient to determine a person's heading.

2. Low Vision and Mobility

Vision is important to maintain a healthy, active life as one ages. Maintaining good vision is important to maintain independence and good quality of life; many of our daily activities, such as walking or driving to the store, cooking, or gardening have strong visual demands. Consequently, impaired vision is one of the most important causes of impaired ability to perform daily activities for Americans aged 70 years and older **[4]**. This emphasizes the relative importance of evaluating factors correlated with good mobility and control of visual motor tasks in low vision patients.

None of the studies so far have assessed the ability of low vision patients to detect radial optic flow information, although two did attempt an indirect measure of optic flow information (**[5], [6]**). These studies have been unable to provide evidence that the information presented in them has had an effect in evaluating patients for orientation and mobility training, modifying training based on individual's abilities or in assessing its effectiveness.

3. Low Vision and Optic Flow

This paper presents an innovative approach to understanding the optic flow processing ability of low vision patients where a series of tests have been written using OpenGL and are being integrated to a Graphical User Interface for analyzing patients with different kinds of visual problems such as age-related macular degeneration, glaucoma, or diabetic retinopathy.

It is innovative primarily because of the subject population. These studies will be the first to use low-vision subjects to determine their ability to detect the focus of expansion (FOE). All the previous studies on focus of expansion have determined the bias, not the sensitivity to focus of expansion. In other words, these tests only determine whether the FOE is to the left or right and take the average. However the calculation of precision was not discussed.

Visual problems such as age-related macular degeneration, glaucoma and diabetic retinopathy represent the three major reasons for visual loss in older Americans and they differ substantially in their visual characteristics. Another reason for selecting these patient groups is the expected differences between the groups in their visual acuity and pattern of visual field loss and what these can tell us about optic flow processing. Patients with age-related macular degeneration may be expected to have primarily central field loss and more severely reduced visual acuity. Patients with glaucoma may be expected to have primarily midperipheral loss and peripheral loss with relatively well preserved visual acuity. Lastly, patients with diabetic retinopathy have a more varied pattern of loss that may be described as a patchy field loss. These studies will serve as a foundation for more realistic future studies, which examine the mobility of low vision patients in simulated environments and investigate the role of higher order visual functions in the control of everyday activities in low vision patients.

Certain assumptions have been made. We assume that

7. The patients will be able to respond to optic flow and its components,
8. Their performance will be impaired compared to age-matched controls with normal vision,
9. The magnitude of impairment will differ for different categories of patients, and
10. The magnitude of impairment will differ based on the visual characteristics of individual patients.

These assumptions appear reasonable given that low vision patients have reduced velocity discrimination **[5]** and detection of motion shear **[6]**.

4. Overview on the Application being developed

The application is being developed using Microsoft Visual Basic 6.0 at the front end which calls several low vision tests being written in OpenGL. The graphical analysis of these tests is provided in the GUI. The results of the tests are stored in an output file to be viewed later for further analysis. These tests are adaptive and hence tend to be difficult or easier based on the user's response. Each test has a specific objective where in the observer views visual patterns on the screen and responds with a left click or a right click.

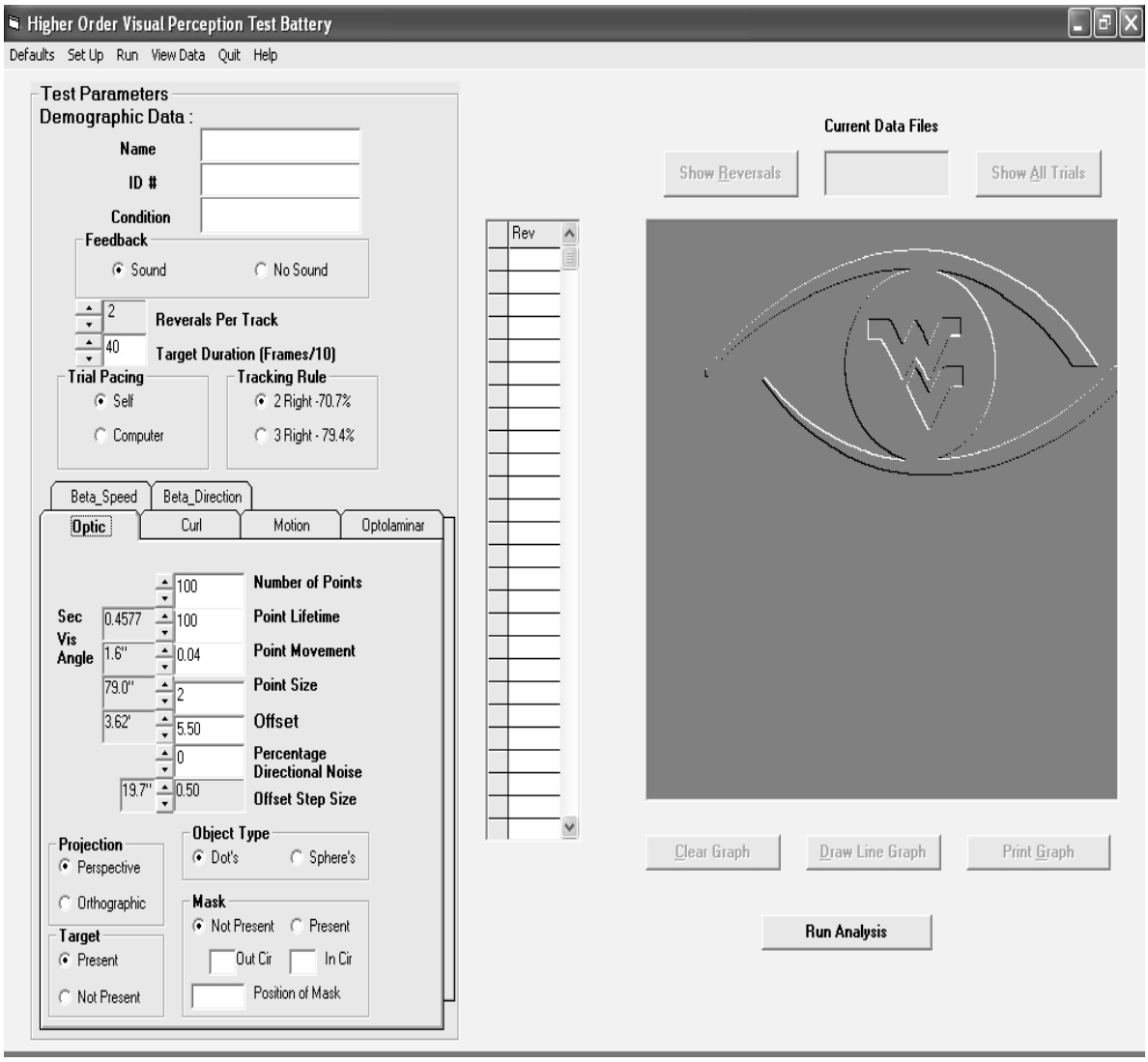

Figure 1. Typical Application Interface

5. Basic Design of the GUI

The application called Higher Order Visual Perception shifts between the GUI and the exe files (to run the experiments). The GUI is developed using Microsoft Visual Basic. On start up, the user initially sees the GUI main screen. The left half of the screen is used to select one of the tests, to set parameter values and enter the demographic data of the user such as the subject Name, ID and Condition. For Graphical analysis of the user's response, the right half of the GUI contains a table and a graph which can display data and results of a particular experiment for further analysis.

In a typical experimental session, the user enters demographic data such as name, a unique ID and his condition, select a test, enter parameters values, and click on the start test button. A window pops up asking whether the parameters for a given test are correct or not. If confirmed the test starts. At this point, the program leaves the graphical MS-Windows environment. After the test runs to the user-specified number of track reversals, control returns to the MS-Windows GUI.

The user may then choose to

1) End the session,
2) Run another test,
3) Review the data from the previous test or
4) Review data from any existing data file.

6. Different Types of Files

There are four basic types of files that are associated with this application for running a session correctly **-.**exe(executable), **.**def(default), **.**par(parameter) and an output Data file(test specific). The contents of the .def and the .par files are either integers or floating point numbers.

6.1 Default files

Various parameter values are required for running these tests successfully, some of which are general and some of which are test specific.

There are two types of parameters-

1. General parameters common for all tests, and
2. Test specific parameters which are accessed by that particular test.

The test specific parameters can be modified in the GUI to conduct that particular experiment with desired parameters. There are seven default files, one for general parameters and one for each of the six test types. Each file contains a set of values for the general or test-specific parameters which appear in the GUI. These files are accessed by the VB shell to load the default values into the GUI. If the .def file is not found, then the GUI loads zeros into the GUI.

The general.def file loads general parameter default values common to all experiments. The default values for a specific test are stored in their respective .def files for e.g. opticflow.def contains the test specific values for the optic flow test. If the test specific parameters are changed in the GUI, they are overwritten in a .par (parameter) file which is accessed by that specific test (exe file) to produce desired pattern (stimuli) on the screen.

In addition to creating new defaults through the GUI, the user can simply edit the default files with a text editor and change values. However, care must be taken to avoid corrupting the formatting, which would make the file unreadable to the GUI.

6.2 Data Files

Also these tests produce an output data file. This output file contains the user's response to these tests. The demographic and test specific data are also recorded. Data files are named XX####.$$ where:
XX refers to the observer initials, #### refers to a random number which is used only as an identifier to ensure that the file has a unique name and $$ refers to the test: "F0" for Optic flow etc.

6.3 Parameter files

When a test starts from the GUI, the parameters are saved to a "parameter file" which is read by the executable test program. The user has no direct control over the creation of these files, but can modify them with a text editor if desired. The parameter files are named say for e.g. woptic.par which means that it is the parameter file for the optic flow test.
Each file contains

4) The values of the parameters set by the user,
5) Demographic data and
6) The name of a new data file to be created.

6.4 Executable files

These files contain the executable code for that particular test. For example woptic.exe is called for running the Optic Flow test without mask. Similarly wcurl.exe is called by the GUI to run the curl or rotational flow test.

7. Overview on Optic Flow

An optic flow module has been developed. It determines people's bias and precision for detecting optic flow. The basic method is similar to others in the literature **[7]**, but the module has added features. Stimuli may be presented with or without a target fixation, with or without masks of arbitrary size and location, and responses may be obtained with or without feedback on correctness. Dots have a variable lifetime and their speed can be varied. The size and the number of dots can also be varied to produce varying visual patterns. The application permits the addition of directional noise, speed noise, rotational or laminar motion, optic flow with laminar flow etc.

7.1 Assessment of Optic Flow thresholds-Threshold determination

The observer looks at a video monitor. A sparse cloud of dots originating from a point (source) and moving outwards is presented on the screen. The FOE (Focus of Expansion) can be located to the left or right of the center of the video monitor. Following stimulus presentation, the person is presented with a fixation target at the center of the screen and asked to indicate by pressing the left or right button of a mouse whether the FOE was to the left or right of the target. Using a dual, adaptive thresholding technique which employs a 2 down 1 up rule, we gradually bring the FOE closer to the center of the screen. Two values are identified, one being the mean for the staircase detecting leftward deviations of the target and one being the mean for the staircase detecting rightward deviations. The midpoint between these two is the Point of Subjective Equality (PSE, Constant Error) and represents the person's bias in estimating the location of the FOE. One half of the distance between the two points estimates the precision of the person's estimate of FOE location.

Thus measuring the bias and precision of FOE judgments provides a more complete picture of patients' performance.

8. Overview on Experiments

Each of the six experiments is written in OpenGL and is adaptive in nature, i.e. the test becomes easier or more difficult based on the user's response to the stimuli. Hence the better an observer keeps performing, the harder the test becomes. If the user does not do well and keeps making frequent mistakes, the test quits based on the number of reversals selected and returns to the GUI.

These tests are written using the OpenGL programming language since most of these patterns are to be represented in a 3-dimensional environment. These tests are adaptive in nature i.e. these tests become difficult/easier based on the user's response.

The Six experiments and their objectives is given below-

1. Detection of Optic Flow - Optic Flow test.
2. Effects of Speed Noise-Beta Speed test.
3. Effects of Directional Noise-Beta Direction test.
4. Effects of Adding Coherent, Laminar Motion - Optolaminar flow test.
5. Detection of Curl or Rotation in Flow - Curl or Rotational Flow test.
6. Detection of Motion Parallax in Laminar Flow- Laminar or Motion test.

8.1 Experiment 1 - Detection of Optic Flow- Optic Flow test

Generation of Optic Flow Stimuli - An Optic flow test has been developed which will serve as the basic foundation for some of the other codes. A set of random dots appear from a source called FOE (Focus of Expansion) and flow outwards in a 3-dimensional field. There is a fixation red line at the center of the screen. The dots appear at random locations to the left or right of the red fixation. If the user keeps judging correctly, the dots move closer to the fixation. The module has some added features. Stimuli may be presented with or without the fixation, with or without masks of arbitrary size and location, and responses may be obtained with or without feedback on correctness. Also noise can be added to these tests to make the task harder. In this experiment, the parameters such as the size and the number of dots, their lifetime, movement, etc are variable and can be increased or decreased between sessions to produce the desired stimuli.

Thus in short, in the optic flow test, the observer views a series of two-alternative, spatial forced-choice trials. Following each trial, the observer indicates whether the target was to the left or right of the fixation mark by pressing the left or right mouse button respectively which is recorded in an output file for further analysis.

8.2 Experiment 2 - Effects of Speed Noise

Adding variability to the speed of radial flow patterns appears to have minimal if any effect in young normal subjects **[11]**. In this experiment, the variability in speeds is obtained by changing the standard deviation of the speed parameter of dots. The mean speed of the dots is maintained constant because of the limitations on the range of speeds that can be obtained. Thus the speed of each dot is different and depends on the shape of the Gaussian function which is a bell shaped curve. The shape of this Gaussian function depends on standard deviation and scale, and hence these parameters decide variability in the speed of the dots.

The parameters such as the number of dots, their lifetime, movement, size, offset, standard deviation and the scaling factor are accepted as the input from the user and speeds are generated based on these input values.

For example, assume the mean speed is 6, the standard deviation is 3 and the scaling factor is 1 would mean that nearly 95% of the dots will have speeds between 4 and 8. Similarly, for a mean speed of 6, if the standard deviation is 3 and the scaling factor is 2 would mean that nearly 95% of the dots will have speeds between 2 and 10 and hence we get more variability in speeds. The user has to choose these parameter values sensibly because speeds less than 1 and greater than 10 have no meaning as they are either too slow or too fast. Also the Gaussian curve can be clipped to obtain limited speeds within a desired range.

The task of the observer in this test is similar to the first test i.e. the observer has to indicate if the FOE is to the left or right of the fixation by clicking left or right mouse button.

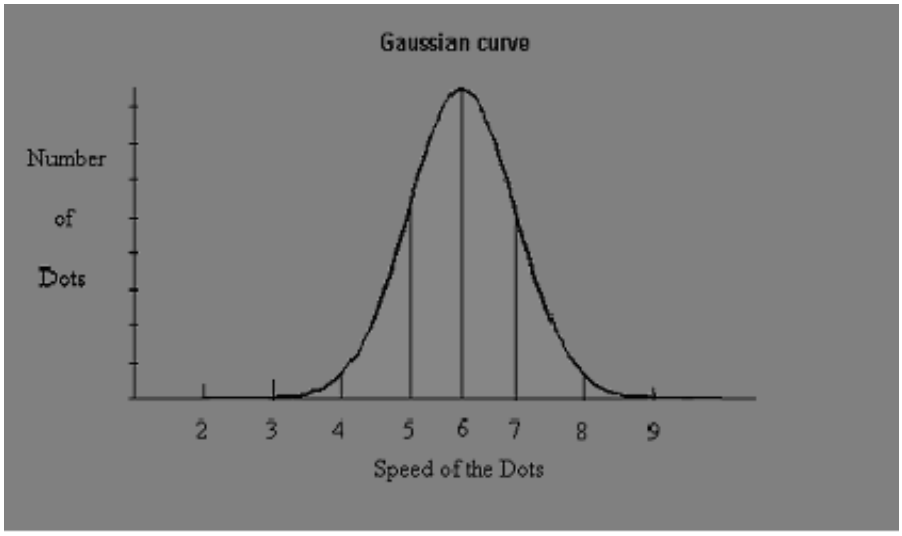

Figure 2. Gaussian Curve with Mean = 6, Standard Deviation = 3 & Scale = 1

8.3 Experiment 3 - Effects of Directional Noise

Adding variability to the direction of the dots in radial flow patterns decreases the precision of judgements of heading in young normal subjects **[11]**. This effect may be greater in case of patients with low vision and other visual defects. Noise is added by varying the standard deviation of the direction of motion of radial flow patterns.

The main aim of the experiment is to change the direction vectors. Let us assume that the dots originate from a point (X_0,Y_0,Z_0) and move towards the user in a particular direction. This is done by adding some directional noise to the source point, i.e. we will vary the point from where the radial flow starts (FOE) by adding some Y-noise and some Z-noise. This causes a change in the direction vectors.

Noise is added according to the Gaussian curve (Bell-shaped curve). The mean of the Y-variation of the source point (FOE) is zero. Thus Standard Deviation (SD) and scaling factors are accepted as input and the FOE point moves up or down during a session with mean = 0. Similarly, the mean Z-variation of source point is -3 because the source point has to be some distance inside the screen i.e. along the negative z-axis. Thus based on the standard deviation and scaling factor, the variation of the source point in the negative z-direction is decided. Note that mean = -3 to make sure that FOE is always inside the screen.

Thus by adding some Y-noise and Z-noise simultaneously along the Gaussian curve, the variability in direction is obtained.

For example, if the Y-SD = 3 and the Scaling Factor = 1, it would mean that more than 95% time, the FOE(Source Point) keeps shifting between -2 and 2 on Y-axis. Similarly if the Z-SD = 3 and Scaling Factor = 1, would mean that more than 95% time, the FOE(Source Point) is between -1 and -5 on Z-axis. With above parameter values, the FOE will mostly lie between -2 and 2 on Y-axis and between -1 and -5 on Z-axis.

The task of the observer is to indicate whether the FOE is to the left or right of the fixation by clicking left or right mouse button. To make the test easier for patients with severe visual problems, it is suggested that the values of SD (Standard Deviation) and Scaling Factor for Y-Noise be small. The user has to be smart enough to choose the standard deviation and scaling factor values for both Y and Z-noise. Also the Gaussian curve can be clipped to limit the movement of FOE within a desired range.

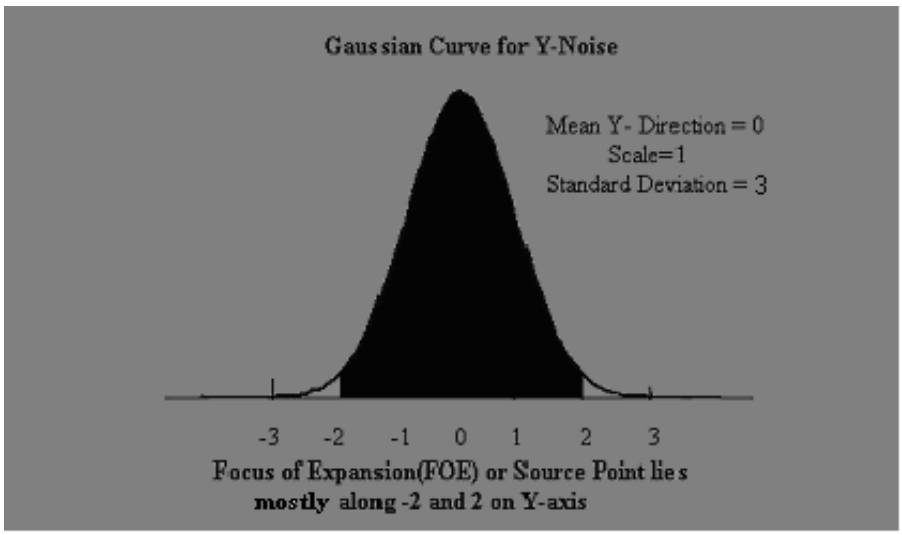

Figure 3. Gaussian Curve with Mean = 0, Scale = 1 and SD = 3

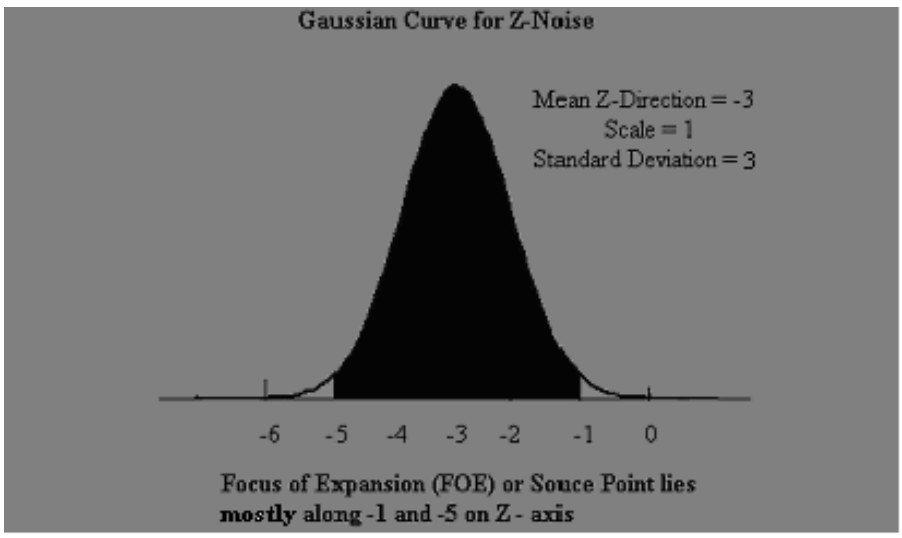

Figure 4. Gaussian Curve with Mean = - 3, Scale = 1 and SD = 3

8.4 Experiment 4 - Effects of Adding Coherent, Laminar Motion

Duffy and Wurtz, **[8]** observed an illusion in heading judgements. If one masked radial flow with a second laminar flow field, the perceived FOE shifted in the direction of laminar (left or right) flow. Others have confirmed the illusion and suggested a variety of mechanisms to account for the effect, including motion capture **[9]** and the properties of populations of neural cells in the primate brain **[10]**.

In this experiment, the radial flow patterns are exactly the same as in optic flow (first experiment), but same or different number of dots moving either to the left or to the right can be added. The constant error and the precision of judgements will be determined separately for the leftward and rightward laminar flow. The direction of the laminar flow can be changed to make the dots flow either to the left or to the right.

The task of the observer is to indicate if the FOE is to the left or right of the fixation, something similar to the first three tests. Here parameters such as the number of radial and laminar dots, speed of laminar flow are variable and can be changed to produce varying visual effects. The direction of laminar flow can also be changed. Parameters such as size of the dots, lifetime of the dots and point movement are also variable and can be increased or decreased between sessions to produce the desired stimuli.

8.5 Experiment 5 - Detection of Curl or Rotation in Flow - Curl or Rotational Flow test

Detection of the direction of Curl or Rotation in optic flow is very useful in detecting shifts in vertical position or sway **[11]**. For example if one tilts to the left there is clockwise (a circular motion to the right) rotation of the field.

Thus in case of curl or rotation of flow, the observer views a cloud of dots which rotate either in clockwise or counter clockwise direction. The observer indicates whether the flow of dots was counter clock wise or clockwise by pressing the left or right mouse button respectively. As the user keeps responding correctly, the test tends to be harder and noise comes into play to confuse the user. The number of dots moving randomly varies and tends to decrease if the observer is not able to judge properly.

The parameters such as the number of dots, size of dots, their lifetime and movement are variable and can be increased or decreased to produce the desired visual pattern.

8.6 Experiment 6 - Detection of Motion Parallax in Laminar Flow- Laminar test

One means of determining relative depth of two objects or planes is motion parallax, i.e. the fact that objects or planes in front of the point or plane of fixation appear to move faster while planes or objects behind fixation appear to move more slowly.

The basic paradigm for the Laminar Motion test is to have four frames with two sets of randomly placed dots. One set of dots moves to the left and the other moves to the right. The speed of dots is faster in one direction.

The task of the observer is to indicate which frame of dots is moving faster by clicking the left mouse button if the dots moving to the left (i.e. from right to left) are faster (or) right mouse button if the dots moving to the right are faster.

Parameters such as the number of dots, size of dots, lifetime, constant and variable speed can be changed across sessions to produce desired visual effects. In this experiment, there are two speeds-constant and variable. Some dots move at constant speed while some move at a variable speed. The variable speed approaches the constant speed as the observer keeps judging correctly and makes the test more difficult.

9. Implementation and Future Work

All the above tests will be used to determine whether patients with visual impairment can respond to optic flow. The following are the objectives-

4. To determine whether people can respond to the stimulus.
5. To determine the response difference between people with visual impairment and those without visual impairment of the same age, if there is any.
6. Finally to determine if subjects with different visual impairment respond distinctively to optic flow detection.

Assuming low-vision patients can respond to optic flow information, and subjects respond distinctively, then more realistic virtual-reality tests can be developed. These tests will be helpful in determining whether or not differences in performance are related to the ability of patients to acquire skills in mobility. Additionally, the virtual environments that will be created may serve as useful training situations for patients with low-vision.

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Effect of Prism Orientation on Heading Detection in Optic Flow

J. VERNON ODOM*†, PRASAD GHUDE† and HOMER HUMBLE†

†Department of Ophthalmology, Robert C. Byrd Health Science Center of West Virginia University, Morgantown, WV. 26506-9193

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*Corresponding Author:

J. Vernon Odom, PhD

Department of Ophthalmology

Robert C. Byrd Health Science Center of West Virginia University

P.O. Box 9193

Morgantown, WV. 26506-9193

Telephone: 1-304-598-6959 Telefacsimile (FAX): 1-304-598-6928

e-mail: jodom@wvu.edu

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Abstract

Purpose: Recent studies of ambulatory behavior indicate that people follow a curvilinear path when moving toward a target and wearing a prism. These results have been interpreted to indicate that heading judgments are based on moving toward a target not on optic flow. This interpretation assumes that if heading judgments were based on optic flow information they would not be altered by prism alignment. We tested this assumption.

Methods: Thirteen observers made heading judgments using a relatively standard optic flow display. Observers were seated 50 cm from a display that subtended 44.6 arc deg in the horizontal dimension. The observers' task was to indicate if the focus of expansion (FOE) was to the right or left of center. A double staircase was employed to determine right and left thresholds for the FOEs. Bias was the mean of the right and left thresholds. Precision was ½ the difference of the right and left thresholds. Observers repeated the judgments 3 times under 3 conditions: no prism and 2 prism conditions (15 diopters binocular, yoked base right and left). A 3x3 Latin square design was used to avoid order effects.

Results: Wearing prisms had a statistically significant effect on subjects' bias ($p < 0.05$) without a statistically significant effect on their precision ($p > 0.10$). As prisms changed from 15 deg base left to 15 deg base right there was a shift to the right in the bias of observers' judgments of about 38 arc min ($p < 0.05$). 11 of the 13 observers showed this change. The precision of judgments of heading was unaffected. The difference between the precision of base left and right judgments averaged about 6 arc min.

Conclusions: Prism orientation affects the bias of heading judgments in optic flow fields. Precision of heading judgments is unaffected.

Key Words: *optic flow, heading, prism, wayfinding*

1 Introduction

Optic flow is the relative change in the positions of objects at different places in the visual field as one moves. Since the pioneering work of Gibson [1,2, also see 3], optic flow has been identified as a major determinant of people's ability to successfully navigate in their environment. In an optic flow field there is a stationary point from which all of the changes flow. The stationary focus of expansion (FoE) is the point toward which the person is heading. Thus, the insight of Gibson was that detecting the FoE was sufficient to determine a person's heading. The simplicity of defining the FoE has lead to considerable research to determine the conditions under which normal observers can accurately detect the FoE and use it to determine their heading.

A number of components of the optic flow field have been identified, including radial inward or outward flow, laminar left or right flow, rotational clockwise or counterclockwise flow and deformation [4]. Theoretical analyses have indicated that optic flow information is sufficient to inform people, animals and machines of the spatial layout of their environment and the direction and heading of themselves and moving or stationary objects [4-6]. These formal mathematical analyses have been important in developing artificial vision algorithms for navigation as well as strategies for the compression of video images [7-9]. Physiological studies have indicated neural areas that appear to be specialized for retrieving optic flow information in insects [10-12], primates [13-17] and humans [18-20].

Optic flow is not the only potential source of information about heading, however. There are numerous potential visual sources of information about heading in natural environments, including, environmental features which serve as landmarks [21-23], and textural characteristics [22]. Optic flow is an imperfect guide to heading. Detection of the FoE can be easily obscured by eye movements or motion along a curvilinear path [24-26] and is subject to illusory effects [15,27,28]. Consequently, it is probable that the human visual system makes use of multiple cues in determining heading and controlling mobility [22,23]. Although optic flow may not be the exclusive clue to heading and direction in wayfinding, there is substantial evidence that under many circumstances human subjects can use the FoE present in optic flow to determine their heading or direction of self-motion [24,25,29,30].

Recent studies of ambulatory behavior indicate that people follow a curvilinear path when moving toward a target and wearing a prism [21, 31-33]. These results have been interpreted to indicate that heading judgments are based on egocentric direction and determined by the perceived location of landmarks and not on optic flow. Other studies indicate that as optic flow cues are increased in salience, the magnitude of the effect decreases [21,32,34]. These studies have generally been interpreted as indicating that optic flow does play an important part in making heading judgments.

All of the reports that have used prisms to dissociate egocentric location from optic flow as determinants of heading assume that heading judgments would be unaffected if optic flow alone were the determinant of heading judgments based on FOE. However, there is a fundamental difference between the stimuli and tasks employed in common experiments used to test heading judgment and those used to evaluate the effects

of prisms. Prism studies observe walking behavior in real or virtual environments. Most optic flow heading experiments have used a dot cloud presented on a video monitor as their stimulus. Presumably the dot cloud display has only optic flow as a potential cue for heading judgments. Therefore any effect of wearing prisms on the judgment of heading would indicate a prismatic effect on heading judgments based on optic flow alone. We tested the assumption that prisms have no effect on heading judgments based solely on optic flow by testing heading judgments using a test field of a dot cloud.

2 Methods

2.1 Subjects

Thirteen observers made heading judgments using a relatively standard optic flow display. The subjects' mean age was 36 years (Range 23-57). All had best corrected visual acuity of 20/20 (1.0) or better.

2.2 Procedure

Observers were seated 50 cm from a display that subtended 44.6 arc deg in the horizontal dimension. The subjects observed a red line at the center of a blank screen. Pressing a mouse began a trial. During the 833 mS trial, the central, red line disappeared and was replaced by an optic flow pattern consisting of 100 dots. Dots appeared at random locations, moving away from a focus of expansion (FOE). Dots had a lifetime of 467 mS or were replaced as they moved off of the screen. At the end of the trial the central, red line reappeared. The observers' task was to determine if the FOE had been to the right or left of the red line. A double staircase was employed to determine a right and left threshold for the FOEs. The threshold to the left of the FOE had a negative sign; the threshold to the right of the FOE had a positive sign. Bias was the mean of the two

thresholds [(L+R)/2]. Precision was half the difference between the right and left thresholds [(L-R)/2].

Observers repeated the judgments three times under three conditions: no prism and 2 prism conditions (15-diopter binocular, yoked base right and base left). Subjects were allowed to adjust their head position in order to re-center the monitor in their field of vision after each placement of trial frames with yoked prisms. A 3x3 Latin square design was used to avoid order effects.

2.3 Data analysis

The mean of the three replications for each condition were used as the basic data. Overall statistical significance was evaluated using an analysis of variance (ANOVA) for repeated measures. Significance of the differences between the means for the base right and base left prism conditions was evaluated using a two-tailed criterion for t-tests for related measures for those measures which had a statistically significant F-test.

3. Results

Wearing prisms had a statistically significant effect on subjects' bias ($F = 4.13$; $df = 2, 12$; $p = 0.028$; see figure 1) without a statistically significant effect on their precision ($F = 0.34$; $df = 2, 12$; $p = 0.7$; see figure 2). As prisms changed from 15 deg yoked base left to 15 deg yoked base right there was a shift to the right in the bias of observers' judgments of 39.25 arc min ($p = 0.045$). In 11 of the 13 observers there was a shift toward the right as the direction of the prism base moved from left to right. Two observers showed the opposite trend. The precision of judgments of heading was unaffected ($p = 0.9$). The difference between the precision of base left and right judgments was 0.082 arc min.

4. Discussion

Prism orientation affects the bias of heading judgments in optic flow fields in our experimental conditions. Precision of heading judgments is unaffected. These results are not consistent with the usual assumption that prisms would have no effect on determining the location of the FOE and optic flow based heading judgments.

There are several possible explanations of this somewhat unexpected finding: 1) there may be a perceived change in the FOE which leads to a perceived change in the direction of heading, 2) there may be aspects of our experimental conditions which introduce artifactual changes, 3) wearing prisms induce systematic changes in head and eye position that may cause systematic changes in heading judgment. We will consider each of these possible sources of our results.

The results are in the opposite direction of the known prismatic effects on perceived object localization and are roughly an order of magnitude smaller. This pattern of results does not support the idea that prisms induce a direct change in the perceived FOE. Prisms bend light toward their base that because of the layout of the retina results in a perceived mislocalization of objects toward their apex. We employed 15-diopter prisms. They displace images approximately 7.5 arc deg toward the base resulting in a perceived change of the image of about 7.5 deg toward the prism apex. Thus the optical change from base left to base right prisms is approximately 15 deg. Our results however indicate that prisms shifted heading judgments in the direction of the prism base and that the total change was only about 40 arc min not 15 degrees.

In order to assist subjects in determining the location of the FOE, we presented a central fixation target before and after the presentation of the optic flow pattern. It is

possible that the presentation of the fixation target could have been affected differently than the effects on the FOE. As indicated above the change in apparent target position would have been much larger than the observed shift in the FOE, a total of about 15 deg rather than about 40 min. While this line of argument cannot totally exclude some effect of the transient presentation of a fixation target, it argues against this as a major cause of a prismatic effect on heading judgments.

In addition to straightforward image displacement, prisms often introduce distortions in the image, e.g. rectangular objects appear more trapezoidal. This implies changes in the apparent velocity of dots, which appear on the larger side of the trapezoid. If dots appear to move more rapidly on one side of a display, this suggests that the FOE is in the opposite direction of the faster motion, i.e., in the direction of the apex of the prism. This effect would be relatively small and in the opposite direction of the observed change.

Wearing prisms has several other effects in addition to their major optical effects. Typically, the person wearing prisms shifts the position of his or her head and the gaze position. Altered head and eye position introduces changes. Changes in head and gaze position are known to introduce systematic errors in the estimation of the FOE [24-26, 35-38]. The direction of these systematic changes is consistent with the observed direction of changes in FOE location with prisms.

In summary, prism orientation affects the bias of heading judgments in optic flow fields without affecting the precision of heading judgments. This is, however, a small effect that is in the opposite direction of changes in perceived image location. The most likely explanation of the effect is that wearing prisms induces an indirect, systematic

error in heading judgment as a result of changes in head and eye position. Because the prismatic effect on heading judgments based solely on optic flow are in the opposite direction of shifts in perceived image location, they may play a role in the apparent reduction in the influence of egocentric localization in determining heading judgments as optic flow cues are increased in salience.

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Figure Caption

1. Effects of Prism Orientation on the Bias of Heading Judgments. The effects of the yoked 15-diopter base right prism, no prism, and yoked 15-diopter base left prism on the bias of judgments are presented, as is the difference between the two prism conditions. Precision is defined as the mean of the heading thresholds for the right and the left. On the ordinate negative numbers indicate bias to the left of center and positive numbers indicate bias to the right of center. Differences are the right bias minus the left bias. Error bars represent 2 standard errors of the mean. On average the bias changes with the prism condition. The change in bias with experimental condition is statistically significant.

2. Effects of Prism Orientation on the Precision of Heading Judgments. The effects of the yoked 15-diopter base right prism, no prism, and yoked 15-diopter base left prism on the precision of judgments are presented, as is the difference between the two prism conditions. Precision is defined as one-half the difference between the heading thresholds for the right and the left. Error bars represent 2 standard errors of the mean. Precision is unaffected by prism orientation.

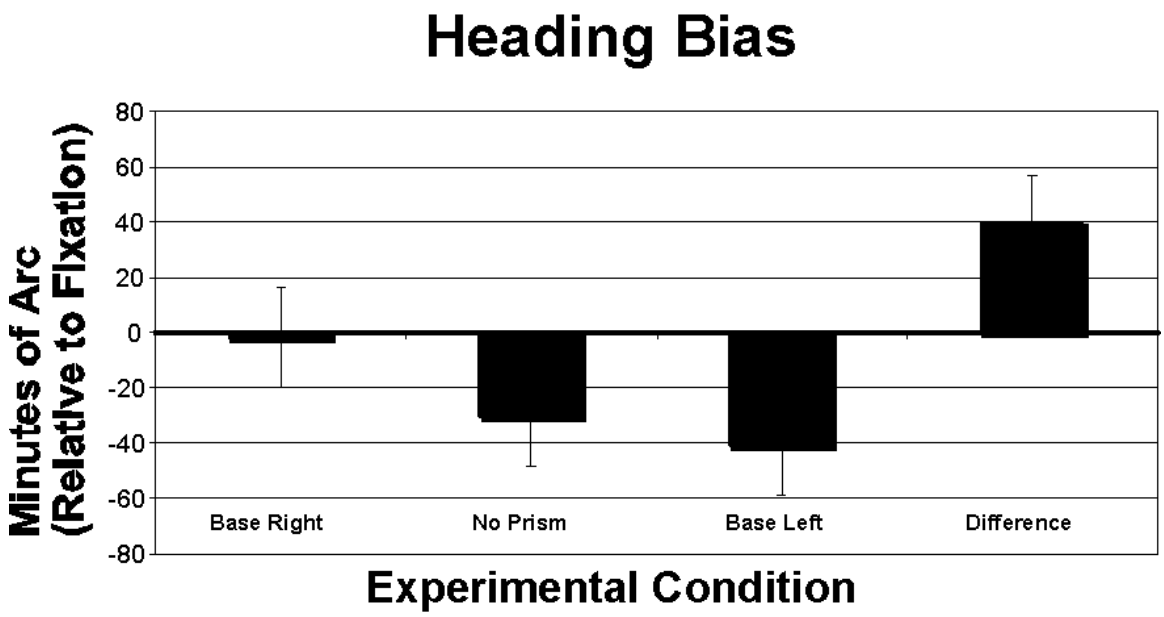

Figure 1. Heading Bias

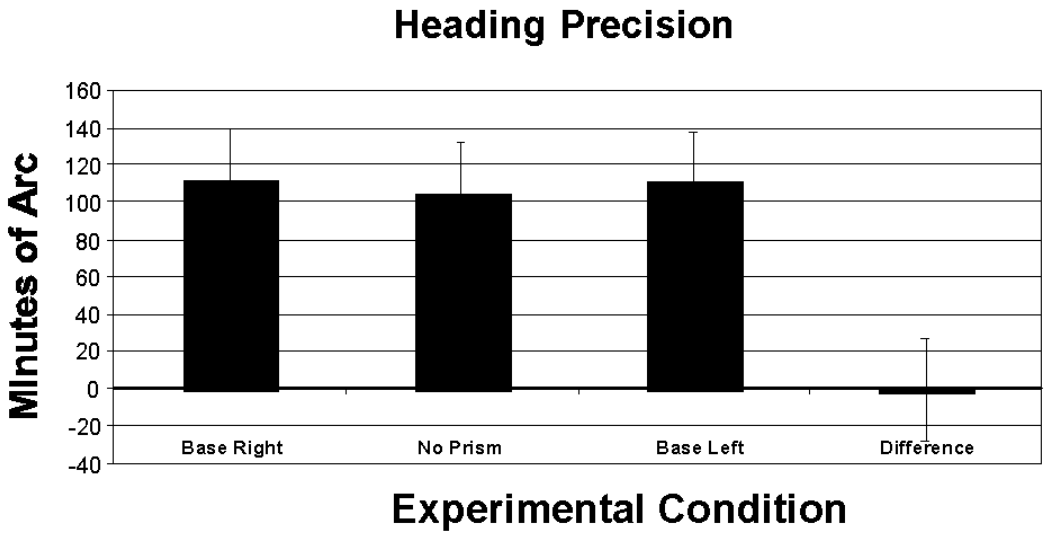

Figure 2. Heading Precision