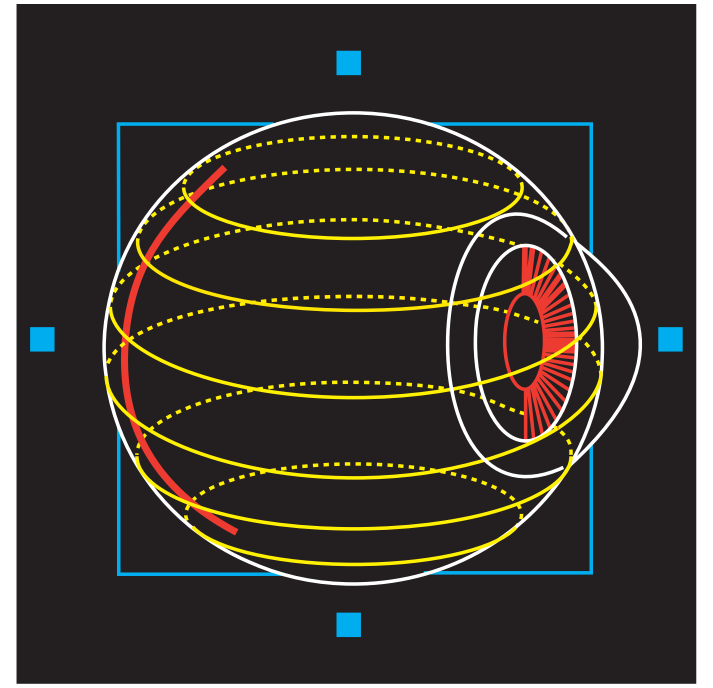

Eye Movements With Peripheral Visual Field Loss While Walking

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ABSTRACT

PURPOSE: To measure and analyze the pattern of eye movements relative to the head under natural conditions of patients with reduced peripheral visual fields. This information will help in the design of mobility visual aids for these patients.

METHOD: We measured the eye position of people while they walked in unfamiliar environments. Three Retinitis Pigmentosa (RP) patients with severely reduced fields (5º to 11º) were tested indoors (large Federal office building or Hospital) and outdoors (city street) and were compared with age-matched normally sighted observers. A head mounted eye-tracking device (I-SCAN) was modified to be portable. It recorded eye position with reference to the head and permitted calibration verification and adjustments along the route. Spatial histograms of eye angular position were calculated.

RESULTS: RP patients' horizontal range of fixation was narrower than those of normally sighted subjects. Patients presented different scanning strategies for indoors (horizontal scanning) and outdoors (vertical scanning). The vertical indoor component was narrower than the vertical outdoor component. When asked about it, patients were aware of the strategy and could explain its reasons.

CONCLUSIONS: The eye movements of subjects with a severely reduced peripheral visual field spanned a smaller angle than normally sighted subjects. Visual aids for peripheral field loss may be effective even with a relatively narrow field of view, if they cover the range of fixation that patients use under normal conditions. Adaptation to even narrower displays is also likely.

INTRODUCTION

"How do tunnel vision patients (TVP) move their eyes during normal walking?"

Where does this question come from?

Designing Visual Aids for patients has to take into account:

- Instantaneous visual field subtended by the aid
- Scotoma generated by the aid (ring, full, or none)
- Field of fixation allowed around the aid (clearance)
- Device ergonomics

- Will the aid restrict normal scanning eye movements?
- Which visual aid size is most appropriate?

Previous clues:

TVP scan the environment using only central vision, possibly resulting in more head/eye movements compared to people with intact peripheral vision.

Tactile aids (long canes) provide information of the lowest space.

General Methods

We recorded eye position with reference to the head of normally sighted and tunnel vision subjects, while walking in unfamiliar environments outdoors and indoors.
We modified an eye tracker to be portable.

Devices

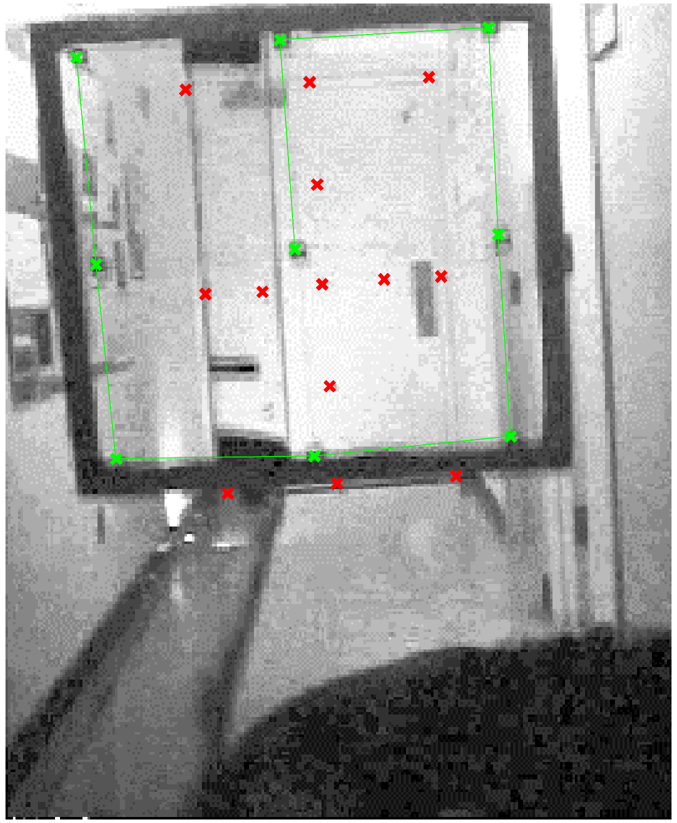
Portable device for pupil position video capture:

- Head mounted monocular eye-tracking device (I-SCAN)
    - Not restricting normal visual field and view
- Modification for portability (everything in a bag)
    - Eye camera output into Canon ZR10 miniDV camcorder
    - Batteries for I-SCAN and camcorder
    - Portable calibration frame mounted in a bite-bar

Video Processing: (Black pupil eye tracker algorithm)

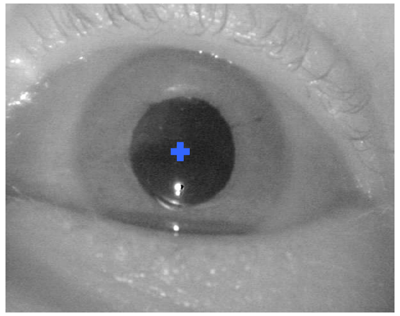
- PC-Board: RK426-PC , 512 (H) × 256 (V) @ 60Hz
- Software: ISCAN® Raw Eye Movement Data Acquisition
- MATLAB to cast data and calculate visual angle from pupil position

PROCEDURE



Comparison between frame and reference grid

- Calibration of point of regard from pupil position (monocular)
  - Characterization of bite-bar calibration frame (once)
  - Eye tracking while fixating 9 points of frame (few seconds)
- Walking about 30 minutes in unfamiliar environments:
  - City Streets (daylight) including street crossing
  - Indoor (illuminated) including stairs
  - Calibration rechecking and adjustment along the route
- Processing video image



  - Tracking of pupil
  - Data casting-rejection and conversion to angular fixation distribution
  - Estimation of standard deviation of angular fixation

CALIBRATION

SCENE CAMERA

Bite-bar frame
9 points
10 cm × 10 cm
at ~ 32 cm

Reference Grid
13 points on the wall
10° (H) × 17° (V)
at 6.5 m

Scene image from a camera conjugated to subject eye while calibrating

Conversion
pixels $(x,y) \Rightarrow$ degrees (α,β)
2^{nd} order polynomial fitting

Reference Grid

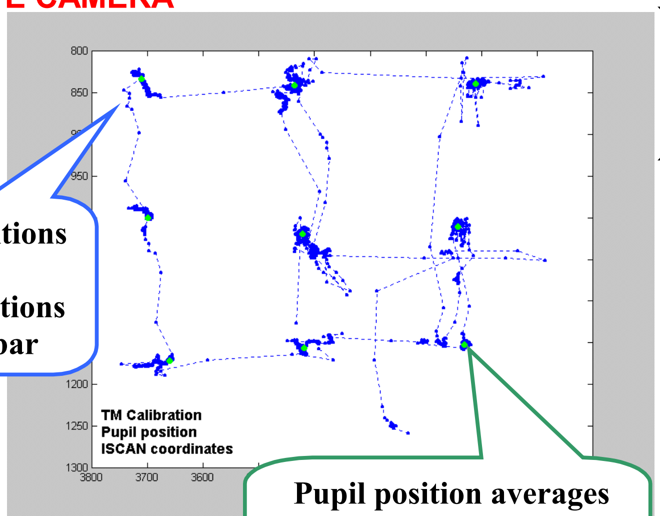
$$\begin{pmatrix}\alpha\\ \beta\end{pmatrix}_{n=1\ldots13} = \sum_{i=0}^{2}\sum_{j=0}^{i}\begin{pmatrix}c\\ d\end{pmatrix}_{ij} x_n^{\,j}\, y_n^{\,i-j}$$

Bite-bar Frame

$$\begin{pmatrix}\alpha^*\\ \beta^*\end{pmatrix}_{m=1\ldots9} = \sum_{i=0}^{2}\sum_{j=0}^{i}\begin{pmatrix}c\\ d\end{pmatrix}_{ij} x_m^{\,j}\, y_m^{\,i-j}$$

EYE CAMERA

Pupil positions
(u,v)
while fixations
to bite-bar



Pupil position averages
while fixating
$(\langle u\rangle,\langle v\rangle)$

Conversion
ISCAN $(u,v) \Rightarrow$ degrees (α,β)
2^{nd} order polynomial fitting

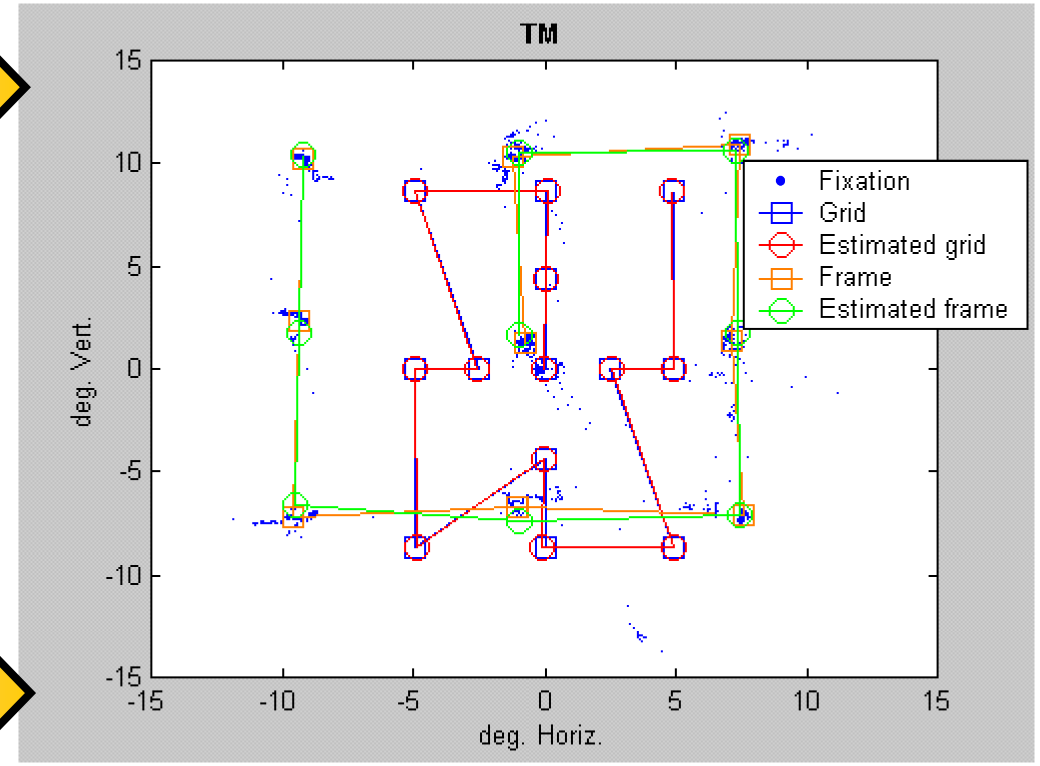
Bite-bar Frame

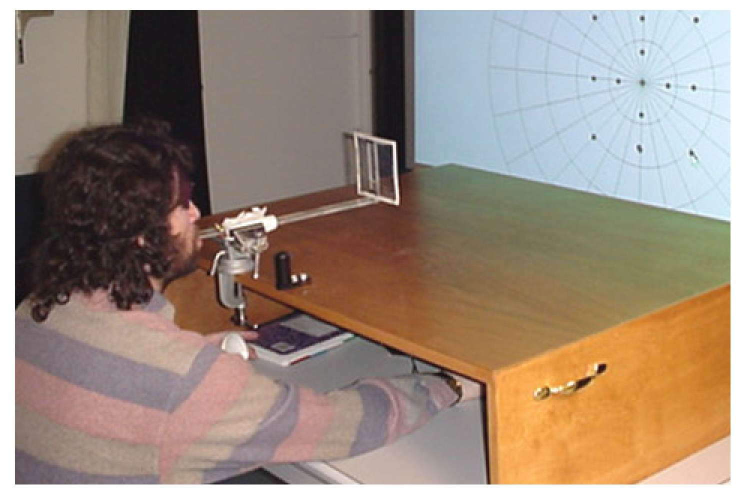
$$\begin{pmatrix}\alpha^*\\ \beta^*\end{pmatrix}_{m=1\ldots9} = \sum_{i=0}^{2}\sum_{j=0}^{i}\begin{pmatrix}e\\ f\end{pmatrix}_{ij} \langle u\rangle_m^{j}\, \langle v\rangle_m^{i-j}$$

Fixations

$$\begin{pmatrix}\alpha^*\\ \beta^*\end{pmatrix} = \sum_{i=0}^{2}\sum_{j=0}^{i}\begin{pmatrix}e\\ f\end{pmatrix}_{ij} u^{j} v^{i-j}$$

CALIBRATION VERIFICATION





Direct angle measurement of frame (perimetry)

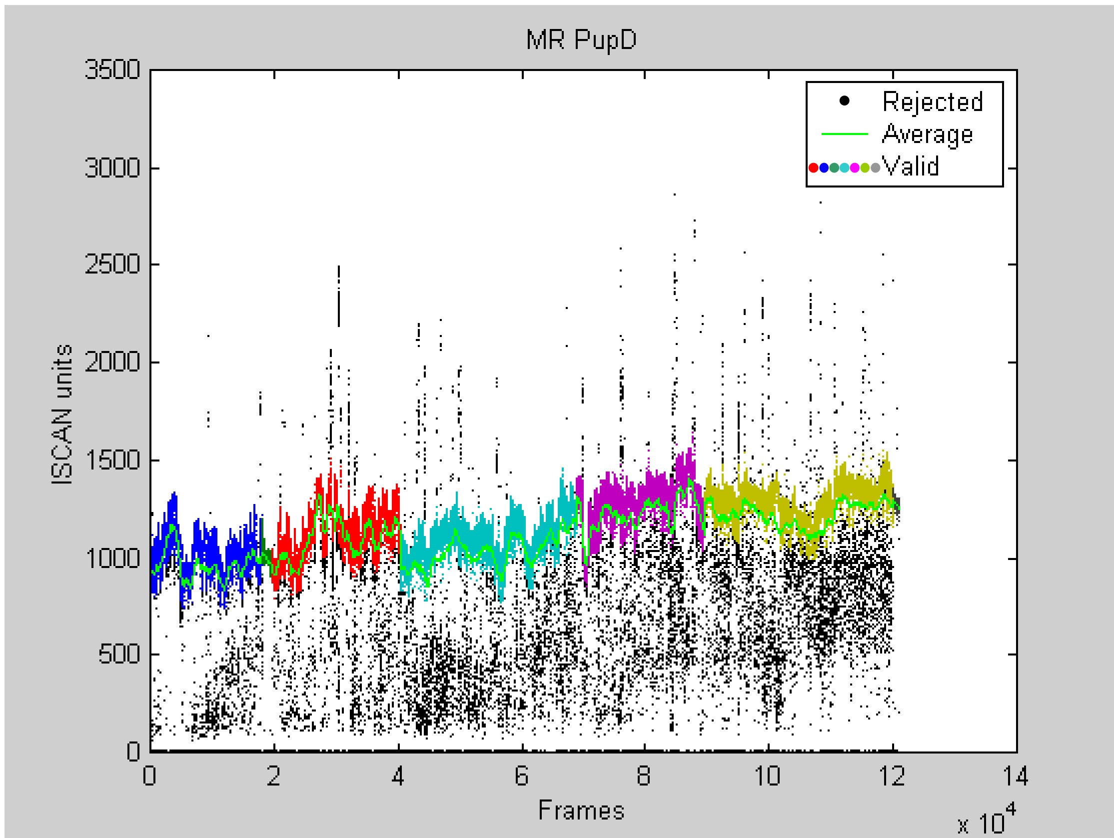
PROCESSING

Data casting-rejection

Because of the uncontrolled environment and the duration of the experiment, ISCAN tracking produced false measurement values mainly due to:

- Blinks
- Lack or too much illumination
- Corneal reflex
- Erratic values

PUPIL DIAMETER DURING RUNS



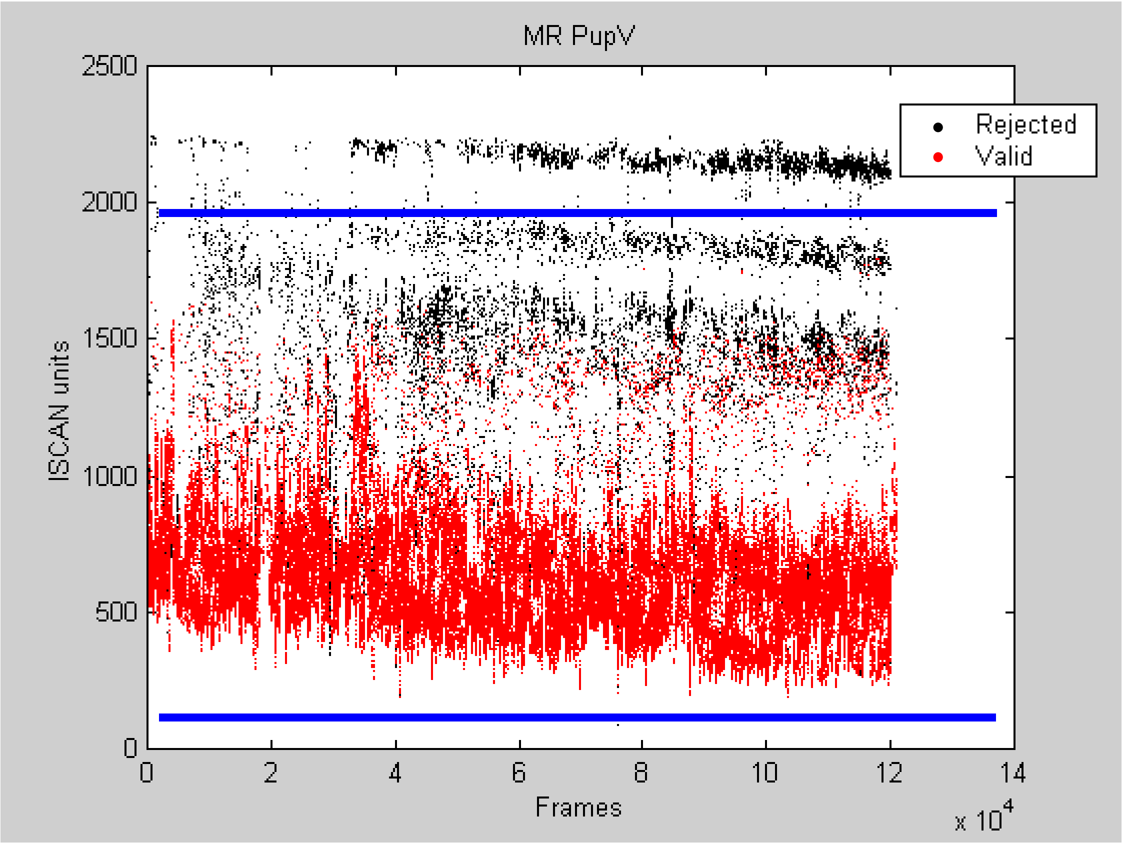
We discarded position data based on:

- <u>Pupil diameter</u>:
  Rejection of values outside of a valid range of pupil diameter
  - Absolute limits to the pupil diameter (1-8 mm)
  - Difference to the diameter average of surrounding 1000 frames

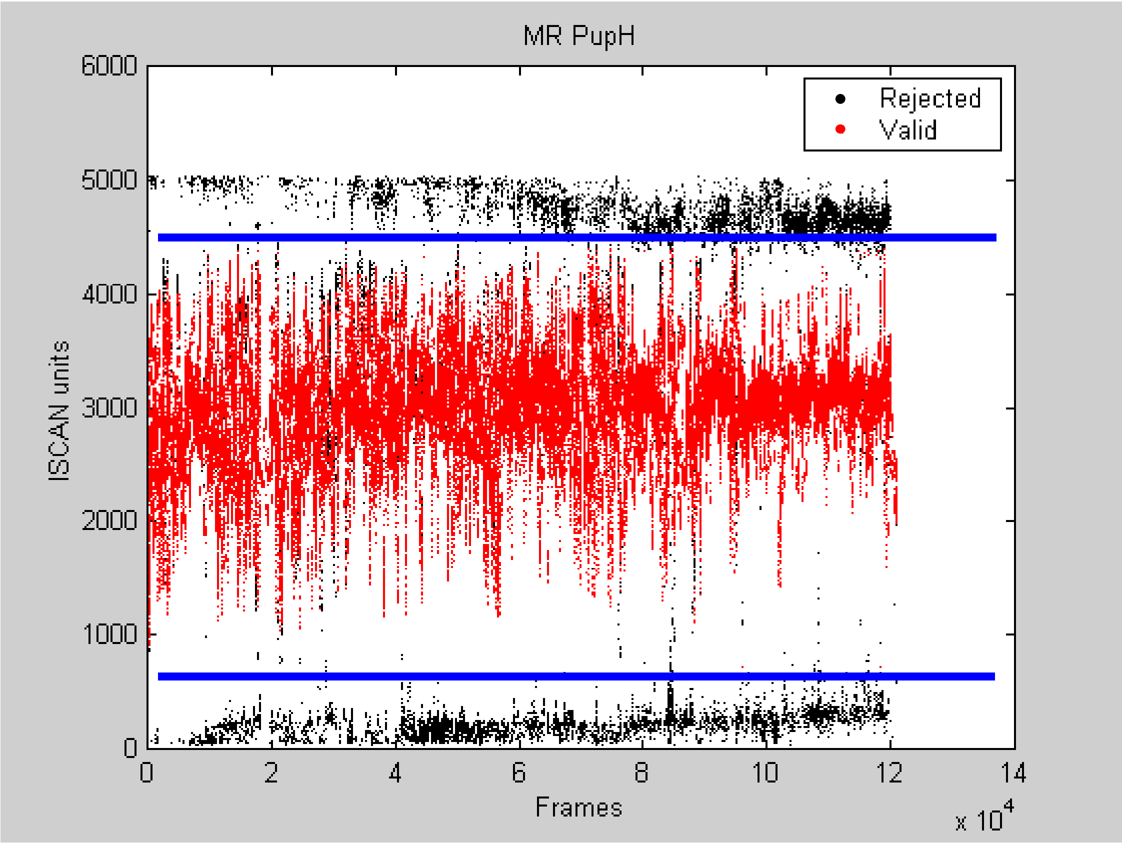
    Empiric rule: compensate bias error to lower values

- Pupil position:
  Window manually set for individual subject data imposing limits to:
  - Vertical position
  - Horizontal position

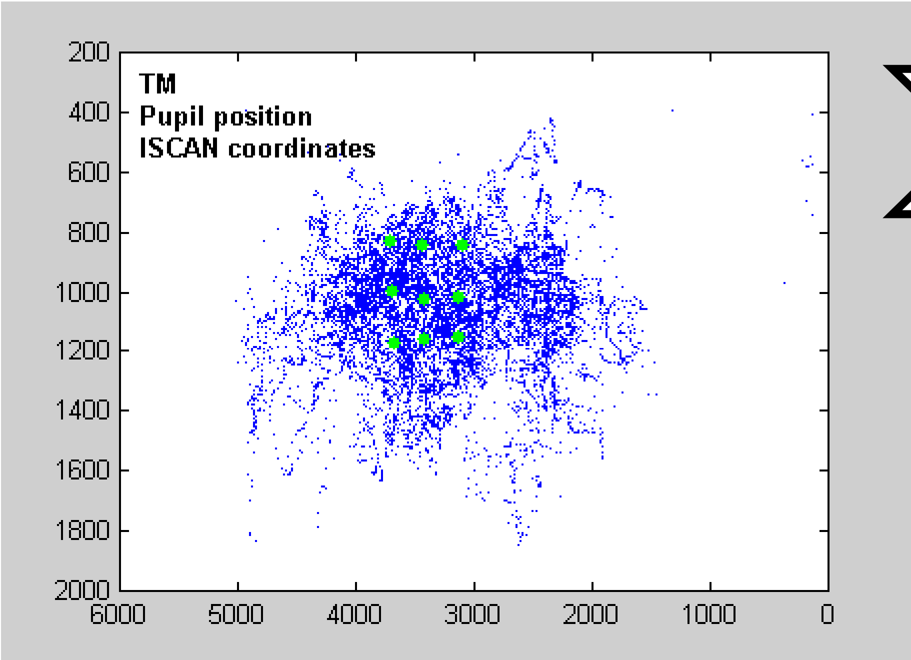
VERTICAL PUPIL POSITION

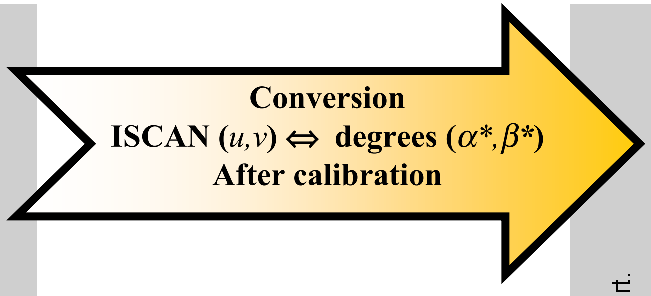


HORIZONTAL PUPIL POSITION



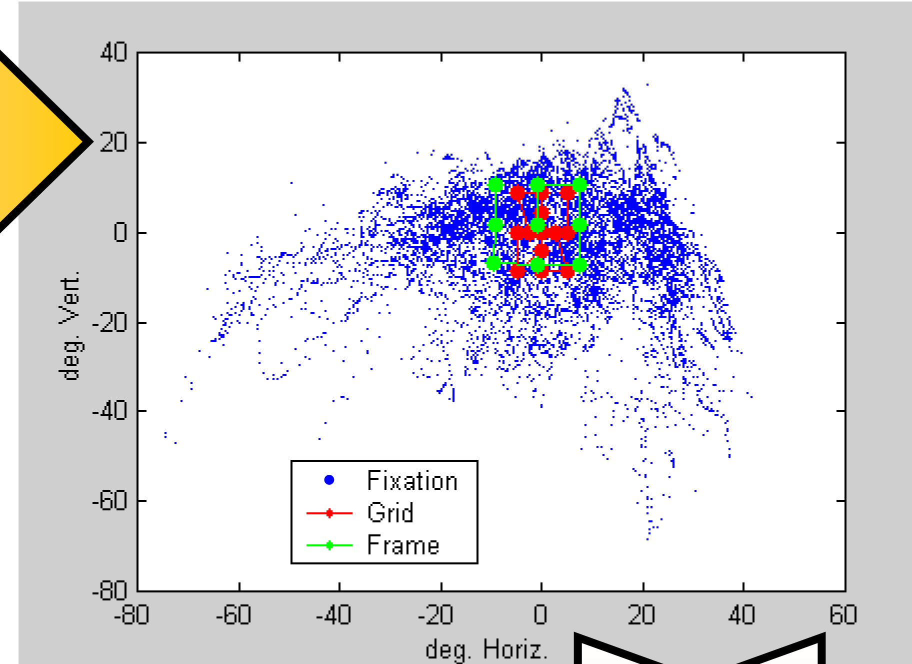
Estimation of fixation distribution





Fixation coordinates

$$\begin{pmatrix}\alpha^*\\ \beta^*\end{pmatrix}=\sum_{i=0}^{2}\sum_{j=0}^{i}\begin{pmatrix}e\\ f\end{pmatrix}_{ij}u^{j}v^{i-j}$$

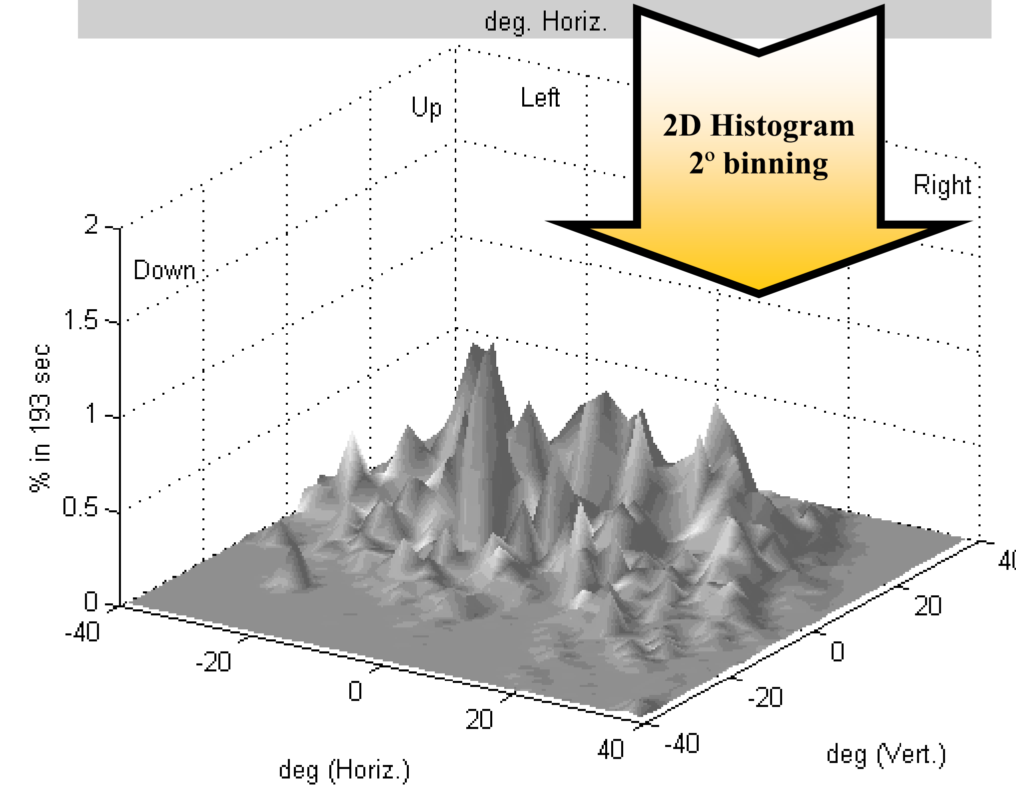


Calculations and gaze spatial histogram

- Reference to mean position of the gaze during the segment (run)
- Computation of sample horizontal and vertical standard deviations as fixation range estimator

$$\begin{pmatrix}\bar{\alpha}^*\\ \bar{\beta}^*\end{pmatrix}_{run}=\frac{\sum_{samples}\begin{pmatrix}\alpha^*\\ \beta^*\end{pmatrix}}{\sum_{samples}1-1}\quad;\quad \begin{pmatrix}S_H\\ S_V\end{pmatrix}_{run}=\sqrt{\frac{\sum_{samples}\left[\begin{pmatrix}\alpha^*\\ \beta^*\end{pmatrix}-\begin{pmatrix}\bar{\alpha}^*\\ \bar{\beta}^*\end{pmatrix}_{run}\right]^2}{\sum_{samples}1-1}}$$

- Binning of eye position into 2º-size square cells



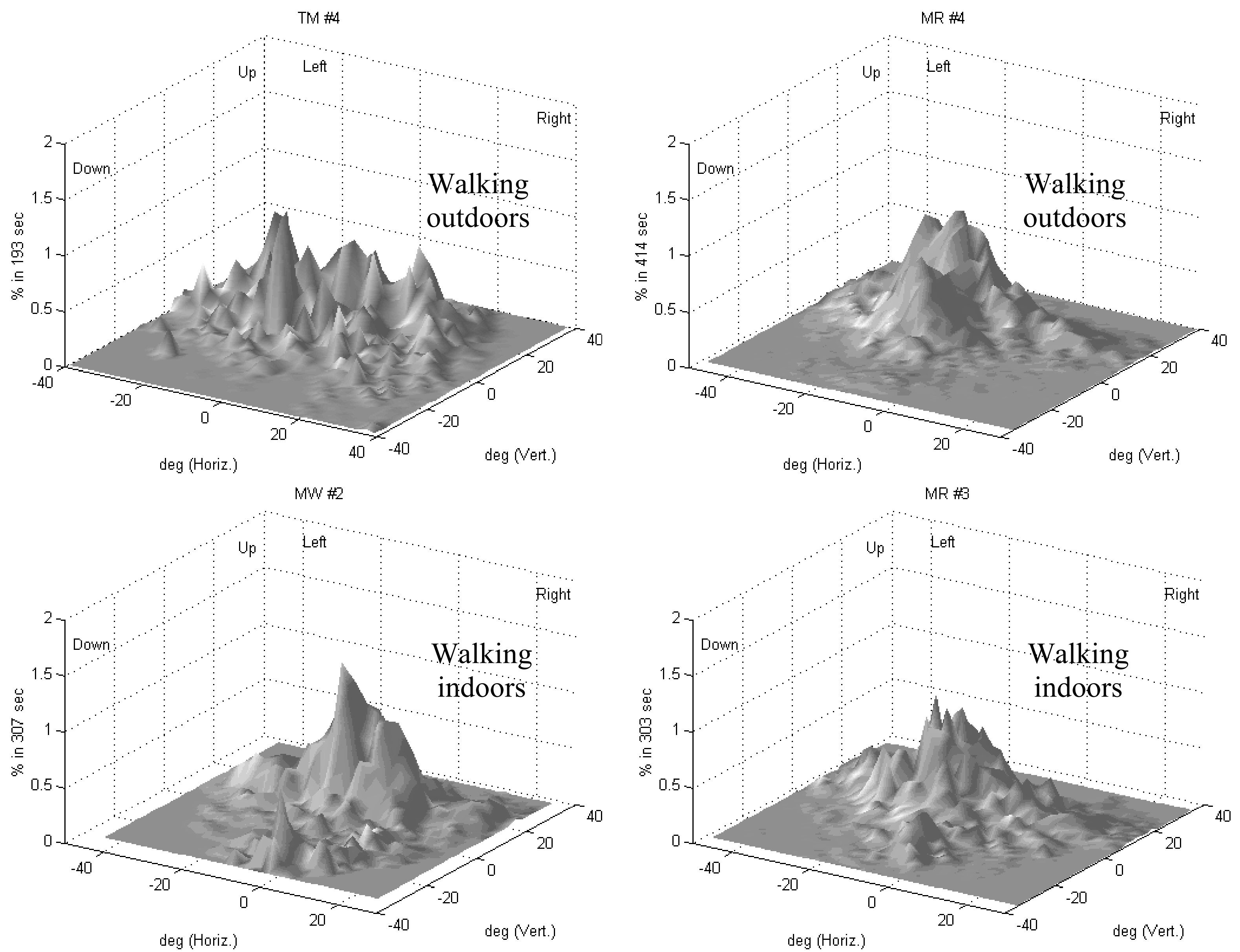
RESULTS

Subjects

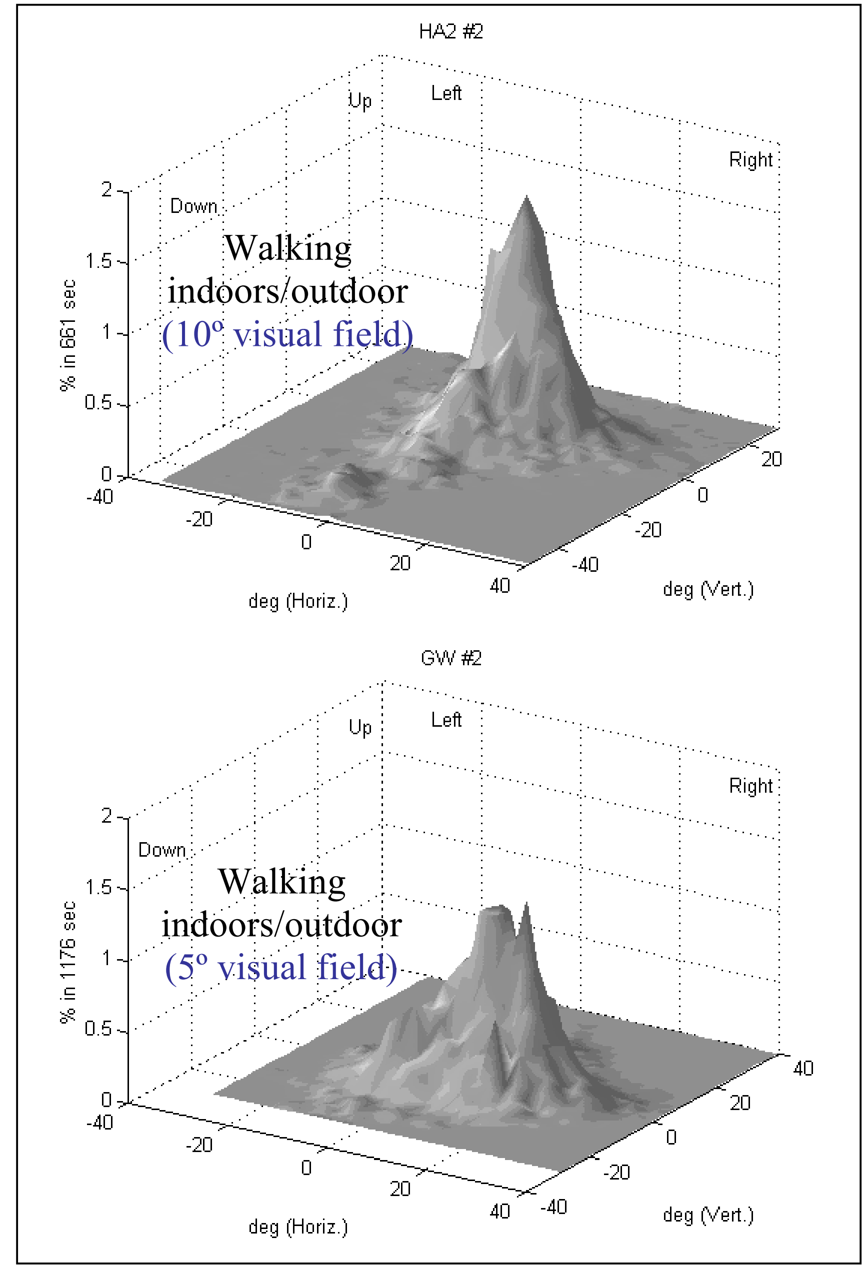
- Three male Retinitis Pigmentosa (RP) patients:
  - Severely reduced fields (5º to 11º field diameter)
  - Good mobility skills Using their tactile aids (if usually used)
- Three normal sighted subjects:
  - Matching age range (50-60 years old)
  - Good mobility skills

	Subject	Environment	S_H (deg)	S_V(deg)	Valid samples	% valid samples	Run Code
Control Subjects	MR	Indoor	16.161	8.1039	16416	91	MR#1
		Indoor	14.389	9.9932	18164	88	MR#3
		Outdoor	13.841	9.9687	24857	87	MR#4
		Indoor	14.744	9.4428	17764	86	MR#5
		Outdoor	8.9547	10.729	25542	84	MR#6
	MW	Indoor	14.082	13.406	18435	90	MW#2
		Outdoor	12.729	6.9585	21776	89	MW#3
		Indoor	14.342	5.9316	20787	92	MW#5
		Outdoor	13.836	8.3341	29898	86	MW#6
		Indoor	13.228	7.9872	6446	90	MW#7
	TM	Outdoor/Indoor	18.58	11.678	12936	26	TM#2
		Outdoor	16.498	11.069	11604	29	TM#4
RP patients	GW (5º)	Indoor/outdoor	9.4362	7.271	70585	74	GW#2
	HA (10º)	PAL reading	4.88	6.9989	23098	93	HA#2
		Outdoor	8.7141	10.3095	16570	91	HA#3
		Indoor	8.2446	5.8393	11967	92	HA#4
		Indoor	8.6849	8.1611	16838	96	HA#5
		Indoor/outdoor	8.5569	10.994	39679	60	HA2#2
		Indoor/outdoor	10.3756	9.7309	32837	41	HA2#4
	WW (11º)	Indoor/outdoor	10.3756	9.7309	35830	70	WW#2
		Outdoor	10.3349	11.1619	5456	11	WW#4
		Outdoor	7.7068	5.9117	1586	8	WW#5
		Indoor	10.6993	4.9798	8038	58	WW#6

Normally sighted observers

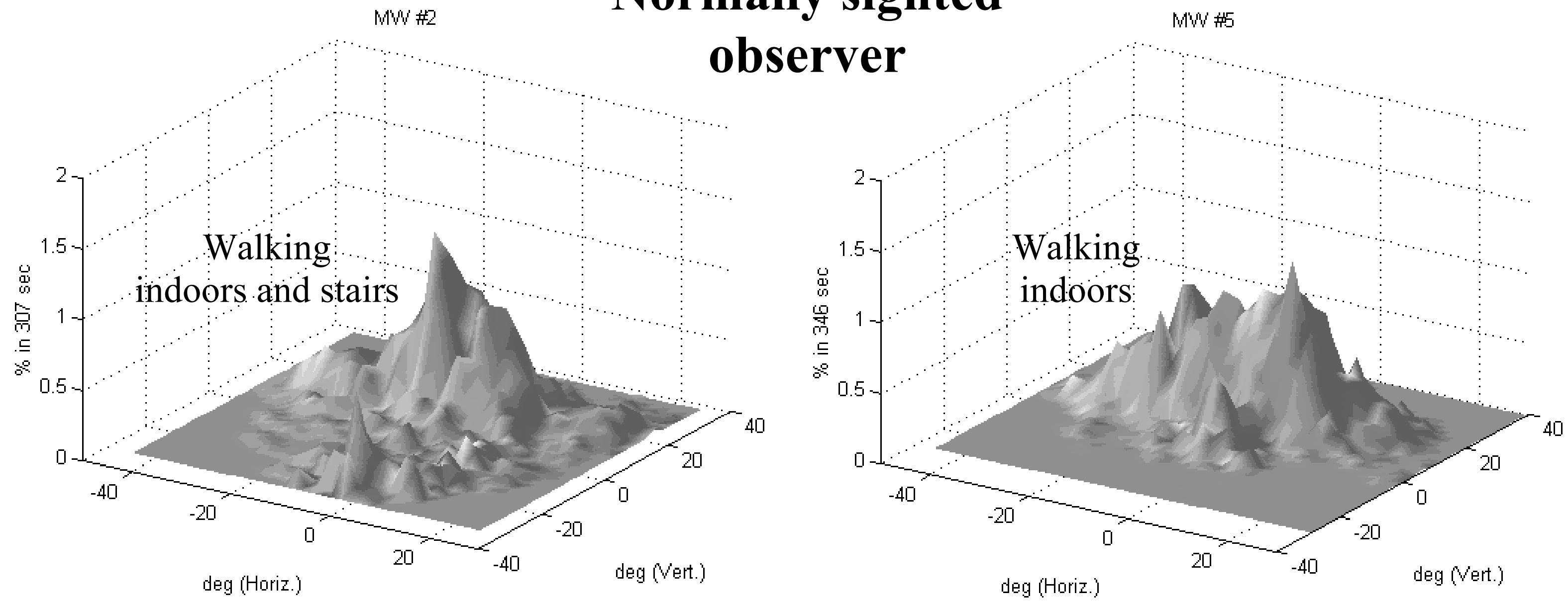


RP patients



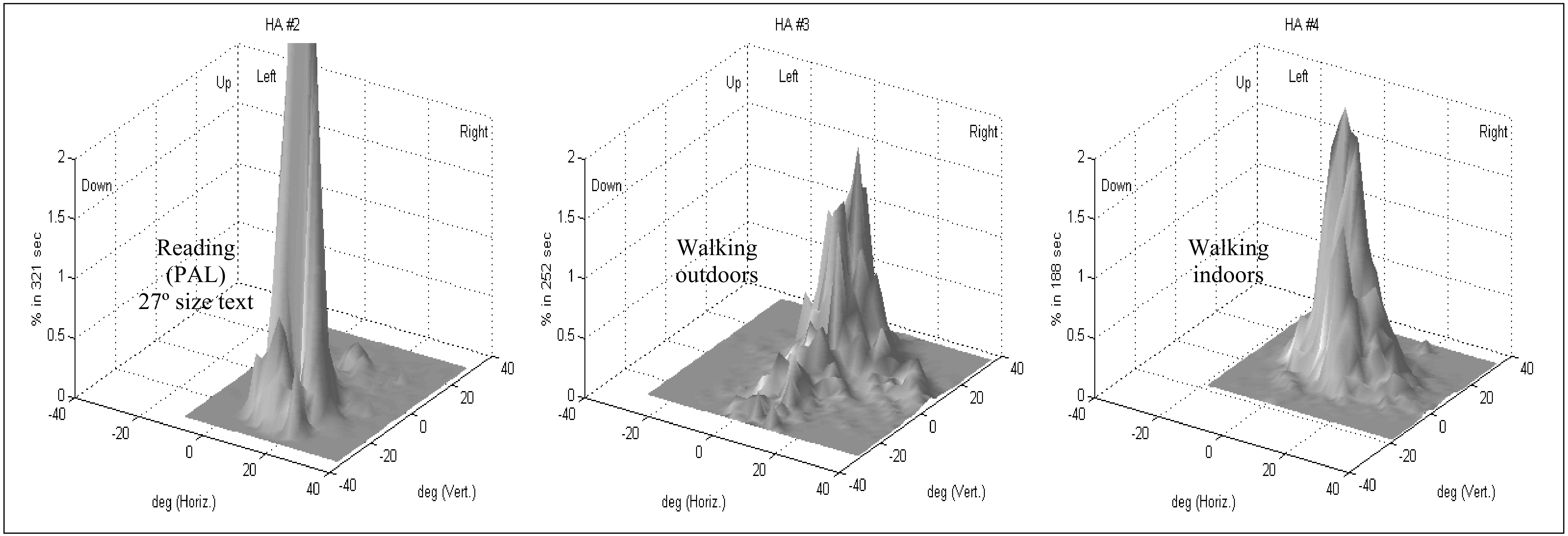
Task difference

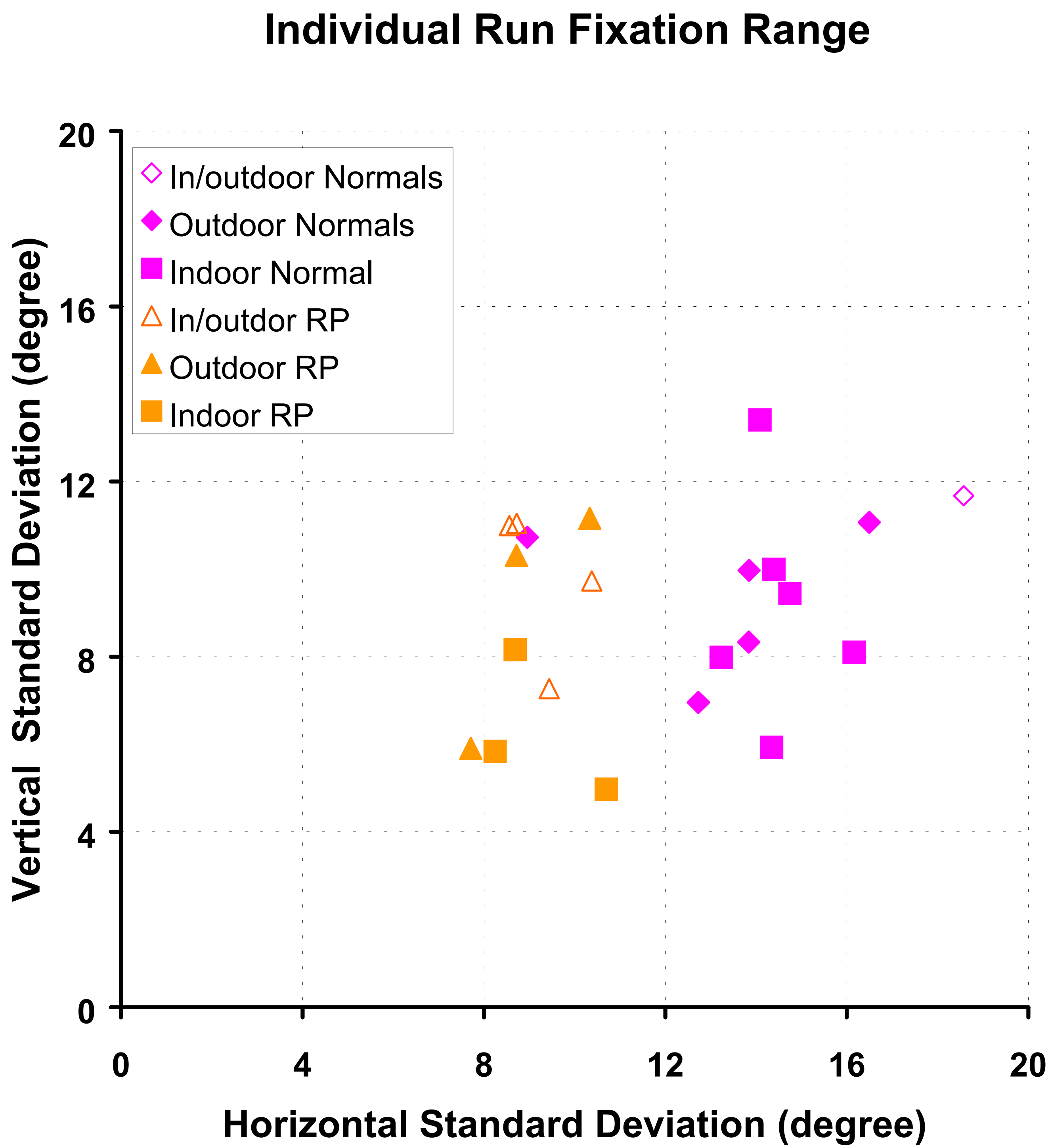
Normally sighted observer



RP patient

(10 deg. visual field)





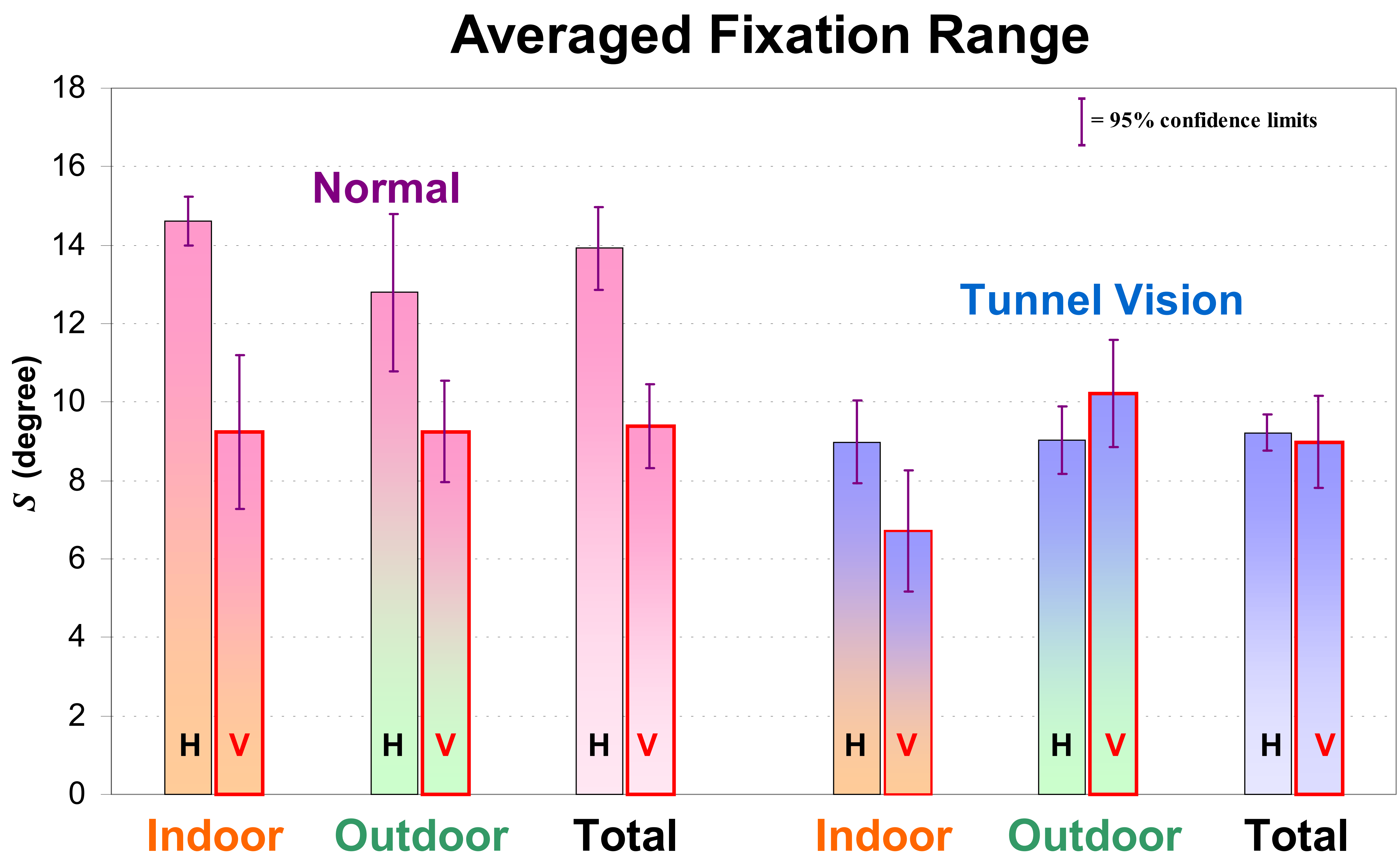
- Individual run fixation range

$$\begin{pmatrix} S_H \\ S_V \end{pmatrix}_{run} = \sqrt{\frac{\sum_{samples}\left[\begin{pmatrix}\alpha^* \\ \beta^*\end{pmatrix} - \begin{pmatrix}\bar{\alpha}^* \\ \bar{\beta}^*\end{pmatrix}_{run}\right]^2}{\sum_{samples} 1 - 1}}$$

- Weighted fixation range average performed across runs, $\bar{S}$

$$\begin{pmatrix} \bar{S}_H \\ \bar{S}_V \end{pmatrix} = \frac{\sum_{run}\left(\sum_{samples} 1\right)\begin{pmatrix} S_H \\ S_V \end{pmatrix}_{run}}{\sum_{run}\sum_{samples} 1}$$

$$\operatorname{var}\begin{pmatrix} \bar{S}_H \\ \bar{S}_V \end{pmatrix} \equiv \frac{\sum_{run}\left(\sum_{samples} 1\right)\left[\begin{pmatrix} S_H \\ S_V \end{pmatrix}_{run} - \begin{pmatrix} \bar{S}_H \\ \bar{S}_V \end{pmatrix}\right]^2}{\sum_{run}\sum_{samples} 1}$$



Averaged Fixation Range
= 95% confidence limits
Normal
Tunnel Vision
S (degree)
0
2
4
6
8
10
12
14
16
18
H
V
Indoor
Outdoor
Total

CONCLUSION & DISCUSSION

- The tested TVP moved their eyes less than the control normal subjects mostly in the horizontal component, possibly due to scanning head movement

  They did not use more scanning eye movement to compensate for their peripheral vision loss, though they may be using head movements

- Differences for some subjects between horizontal and vertical scanning behavior in outdoor/indoor caused by difference in navigating tasks
  - Indoor: looking at walls and door ways
  - Outdoor: aware of sidewalk obstacles (increase of vertical fixation range)

  The use of tactile aids (long cane) provide information on the lower space

- Visual aids for peripheral field loss may be effective even with a relatively narrow field of view ($2\times\bar{S} \approx 15^{o}$-$20^{o}$), if they cover the fixation range that patients use under normal conditions. Adaptation to even narrower displays is also possible

FUTURE WORKS

- Evaluation of adaptation to visual aids subtending narrow visual field
- Study of the effect of the visual field size in the fixation range used by TVP in specific visual tasks
- Determination of gaze profiles in binocular hemianopes (lateral restricted field)

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COMMENTS

Please, give us your comments and suggestions