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 (5° to 11°) 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

• Calibration of point of regard from pupil position (monocular)
  o Characterization of bite-bar calibration frame (once)
  o Eye tracking while fixating 9 points of frame (few seconds)

• Walking about 30 minutes in unfamiliar environments:
  o City Streets (daylight) including street crossing
  o Indoor (illuminated) including stairs
  o Calibration rechecking and adjustment along the route

• Processing video image
  o Tracking of pupil
  o Data casting-rejection and conversion to angular fixation distribution
  o 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

EYE CAMERA

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

Pupil position averages
while fixating (〈u〉,〈v〉)

Conversion
pixels (x,y) ⇒ degrees (α,β)
2nd order polynomial fitting

Reference Grid

\[
\begin{align*}
\alpha & = \sum_{i=1}^{2} \sum_{j=1}^{13} c_{ij} x_{i} y_{j}^{-1} \\
\beta & = \sum_{i=1}^{2} \sum_{j=1}^{13} d_{ij} x_{i} y_{j}^{-1}
\end{align*}
\]

Bite-bar Frame

\[
\begin{align*}
\alpha' & = \sum_{i=1}^{2} \sum_{j=1}^{9} e_{ij} x_{i} y_{j}^{-1} \\
\beta' & = \sum_{i=1}^{2} \sum_{j=1}^{9} f_{ij} x_{i} y_{j}^{-1}
\end{align*}
\]

Conversion
ISCAN (u,v) ⇒ degrees (α,β)
2nd order polynomial fitting

Fixations

\[
\begin{align*}
\alpha & = \sum_{i=0}^{2} \sum_{j=0}^{9} e_{ij} u_{i} v_{j}^{-1} \\
\beta & = \sum_{i=0}^{2} \sum_{j=0}^{9} f_{ij} u_{i} v_{j}^{-1}
\end{align*}
\]

Direct angle measurement of frame (perimetry)

CALIBRATION VERIFICATION
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

We discarded position data based on:

• Pupil diameter:
  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:
  o Vertical position
  o Horizontal position

[Graphs showing vertical and horizontal pupil position over time with limits indicated]
Estimation of fixation distribution

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

\[
\begin{align*}
(\bar{\alpha}^*, \bar{\beta}^*)_{\text{run}} &= \frac{\sum_{\text{samples}} (\alpha^*)^2}{\sum_{\text{samples}} (\beta^*)^2} : \frac{\sum_{\text{samples}} (\alpha^*) (\beta^*)}{\sum_{\text{samples}} (\beta^*)} \\
S_{\text{run}}^2 &= \left( \frac{\sum_{\text{samples}} (\alpha^*) (\beta^*)}{\sum_{\text{samples}} (\beta^*)} \right)^2
\end{align*}
\]

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

Conversion
ISCAN (u, v) ⇔ degrees (\(\alpha^*, \beta^*\))
After calibration

2D Histogram
2º binning
RESULTS

Subjects

• Three male Retinitis Pigmentosa (RP) patients:
  • Severely reduced fields (5° to 11° 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

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<th>Subject</th>
<th>Environment</th>
<th>$S_H$ (deg)</th>
<th>$S_V$ (deg)</th>
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Walking indoors/outdoor

Normally sighted observers

Walking outdoors

Walking indoors

Walking indoors/outdoor (10º visual field)

RP patients

Walking indoors/outdoor (5º visual field)
Task difference

RP patient
(10 deg. visual field)
• Individual run fixation range

\[
\left( \frac{S_H}{S_V} \right)_{\text{run}} = \sqrt{\frac{\sum_{\text{samples}} \left( \alpha^* \cdot \beta^* - \bar{\beta}^* \right)^2}{\sum_{\text{samples}} \sum_{1-1}}}
\]

• Weighted fixation range average performed across runs, \( \bar{S} \)

\[
\left( \frac{\bar{S}_H}{\bar{S}_V} \right) = \frac{\sum_{\text{run}} \sum_{\text{samples}} \left( \frac{S_H}{S_V} \right)_{\text{run}}}{\sum_{\text{run}} \sum_{\text{samples}}}
\]

\[
\text{var} \left( \frac{\bar{S}_H}{\bar{S}_V} \right) = \frac{\sum_{\text{run}} \sum_{\text{samples}} \left( \frac{S_H}{S_V} \right)_{\text{run}} - \left( \frac{\bar{S}_H}{\bar{S}_V} \right)}{\sum_{\text{run}} \sum_{\text{samples}}}
\]
Averaged Fixation Range

Tunnel Vision

= 95% confidence limits
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 ($2 \times \bar{S} \approx 15^\circ$-$20^\circ$), 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)

ACKNOWLEDGEMENT

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COMMENTS

👍👎 Please, give us your comments and suggestions📝