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Patients with tunnel vision frequently saccade beyond their visual fields in visual search

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Abstract (updated)

- **Patients with severely limited peripheral vision ("tunnel vision") performed a simple visual search task**
  - **9 subjects with horizontal visual field (VF) diameter 8º - 16º.**
  - **They searched for "pop out" targets on a projection screen (66ºx54º).**
  - **2 cue conditions (with or without auditory position cues to the octant containing a target), and 2 backgrounds (blank or street scenes) were tested.**
  - **Head and eye movements were recorded.**
- **The frequency of saccades > 4º decreased exponentially with saccade amplitude.**
- **About one-third of saccades were to areas outside of their visual fields.**
- **The patients reported they could maintain good orientation across saccades.**
- **No effect of auditory cue or structured background on saccades was found in the visual search.**
- **Conclusion: Many saccades were not elicited by visual information in the view at the saccade onset.**

Background

- **Normally, salient features in the periphery attract visual attention and elicit saccades.**
- **Saccades direct the fovea to areas of interest.**
- **Visual perception is ineffective during saccades. Fixations are like snapshots.**
- **Retinitis pigmentosa and choroideremia can cause severe peripheral vision loss (tunnel vision). Many patients at end stage have visual fields smaller than 15º in diameter.**
- **Questions: In the presence of tunnel vision, will saccadic behavior be affected? Can patients maintain orientation when snapshots are not overlapped? Can patients perceive a stable world?**
- **We analyzed the eye movement data from a visual search experiment we conducted using patients with tunnel vision (Luo, et al., In press), in which different cue and background conditions were tested.**

Methods

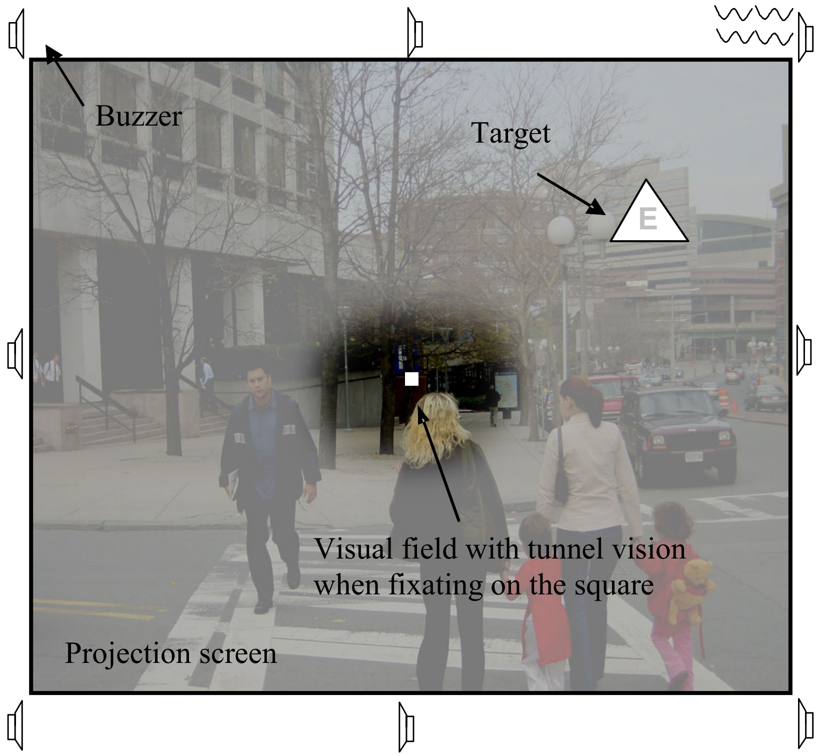

Figure 1. A diagram of the visual search task performed by subjects with tunnel vision. Targets were presented outside their visual fields. Auditory cues were provided by 8 buzzers placed around the projection screen, which indicated the approximate directions of targets. The area shown in pale color represents a typical area invisible to subjects when fixating the central target.

- **9 subjects (VF size: 8º-16º; VA: 0.0-0.4 logMAR) searched for targets presented outside their visual fields.**
- **Screen size 66º (H) by 54º (V); 60 targets (3º or 5º) at eccentricities of 15º, 22º, and 29º in randomized directions.**
- **The search area background was either blank or one of 16 color pictures of street scenes.**
- **4 sessions per subject: 2 background conditions (blank and picture) X 2 cue conditions (with and without auditory cues)**
- **Free eye and head movements allowed. Positions of head and eye were recorded at 60 Hz to identify gaze point.**
- **Search segment from initial movement to the point at which the target was foveated was analyzed.**

Results: Saccade frequency vs. amplitude

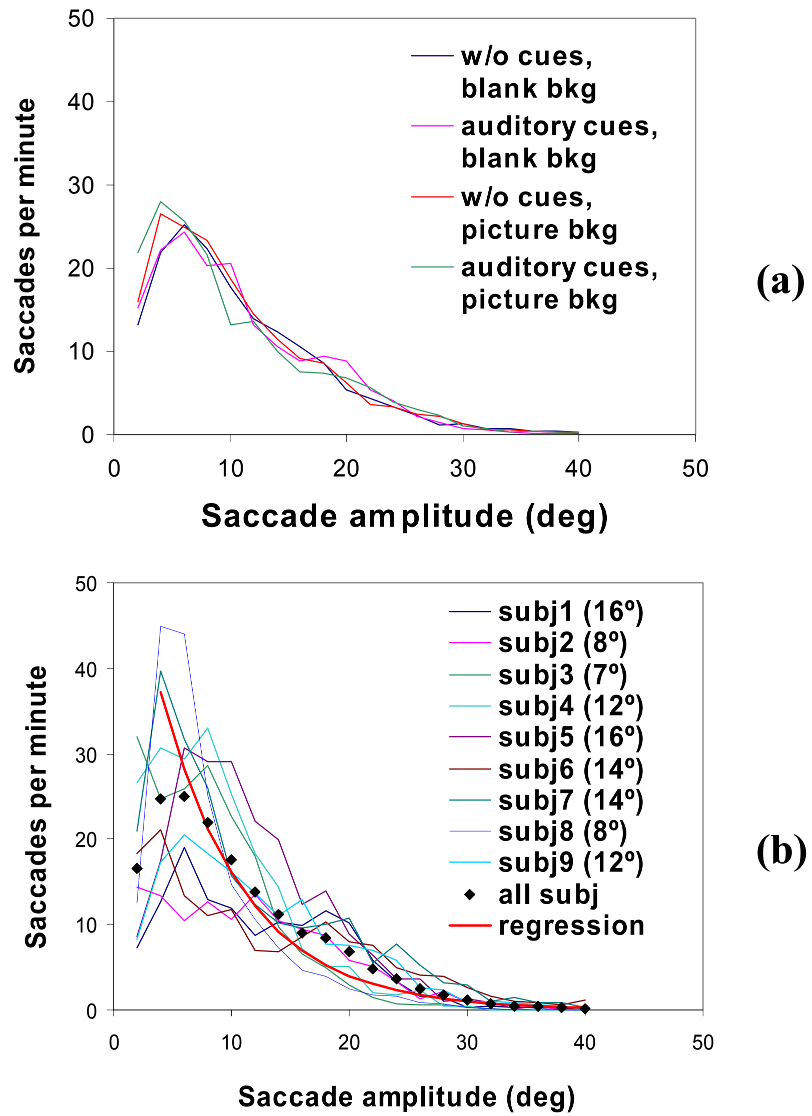

Figure 2. Saccade frequency vs. amplitude: (a) collapsed across subjects; (b) collapsed across sessions (subjects' VFs are given).

- **The saccade frequency was very similar for different background and cue conditions (Fig. 2a), but different between subjects (Fig. 2b).**
- **An exponential model was fitted to the relationship between saccade frequency and saccade amplitude (R^2=0.97) for saccades > 4º:**

$$S=65.2\times\exp(-A / 7.14),$$

S: **Saccades per minute**
A: **Saccade amplitude in degrees.**
Saccades <4º were not used because they are less relevant to this study, and the detection is very sensitive to criteria.

- **Decay coefficient (7.14) indicates the speed of decrease. Bahill, et al. (1975) reported a similar decay coefficient, 7.6, for normally-sighted subjects walking through a campus.**
- **Correlation between VF and decay coefficient was not significant (Pearson r=0.27).**

Results: Saccade statistics

Table 1. Average saccade frequencies (±SD)
NB: without cue and blank background
AB: auditory cues and blank background
NP: without cue and picture background
AP: and auditory cues and picture background

	NB	AB	NP	AP
Saccades/min (total)	167±34	169±41	175±33	174±39
Saccades/min (beyond VF)	54±19	58±22	53±17	53±18
% of saccades (beyond VF)	35±17	37±18	32±13	31±9

- **About one-third of saccades were to areas invisible at the saccade onset!**
- **Saccade frequency was not affected by the cue and background conditions (repeated measures ANOVA, $F_{1,8}<2.8$, $p>0.13$)**

- **No significant correlation between saccade frequency and VF size (Pearson r<0.35)**

Table 2. Average fixation durations (±SD). Unit: ms.

	Without cues	Auditory cues
Blank bkgd	140±7	121±12
Picture bkgd	145±10	120±8

- **Background did not affect fixation duration (p=0.81).**
- **Auditory cues reduced fixation duration by 15% (repeated measures ANOVA, $F_{1,8}=16$, $p=0.004$).**
- **VA (Pearson r<0.45) and VF (Pearson r<0.3) were not significantly correlated with fixation duration.**

Discussion

- We conclude that many saccades in visual searches, especially those larger than VF, were planned based on mental maps and search strategies instead of information visible at saccade onset.
- We think patients probably could maintain good orientation across saccades based on their reports and the fact that so many of their saccades were beyond VFs.
- Saccades are spatially encoded (Mays & Sparks, 1980). Patients with hemispatial neglect tend to fail to make saccades to the neglected side, while hemianopes do saccade into the blind side (Husain, et al., 2001). It is likely that saccades can be planned as long as the spatial representation of the environment has been established, and visible information is not necessarily needed.
- Q: What caused the exponential distribution of the relationship between saccade frequency and amplitude?
- Q: Why were the distributions for patients and normally-sighted people similar?
- Large saccades resulted in non-overlapping snapshots. Further studies are needed to investigate the reasons they did so instead of making snapshots overlap, and the efficiency of such a strategy.

Visual stability

- **Saccadic eye movements result in fast image displacement on the retina, yet we perceive a stable world. How we are able to do so is not completely resolved. Theories have been proposed:**
    - **Cancellation using extraretinal signals (von Holst & Mittelstaedt, 1971)**

      There is physiological evidence of parietal remapping before saccade onset (possibly based on extraretinal signals) (Duhamel, et al., 1992), but the accuracy of extraretinal signals seems to be too low to account for visual stability (Matin, 1986)
    - **Trans-saccadic integration (Jonides, et al., 1982)**

      Some visual information can be carried over across saccades (Melcher, 2005), which probably could be used for registration of "snapshots" across fixations.
- **Are questions of visual stability applicable to patients with tunnel vision?**
- **Patients never get confused between scene shifts and retinal image shifts that result from saccades. Extraretinal signals are probably a critical factor accounting for this.**
- **Trans-saccadic integration cannot happen to the patients when two "snapshots" do not overlap. However, saccades beyond their VFs do not prevent perception of a "stable world", as patients self-reported. Their perception might be just based on knowledge or assumption. If so, do normally-sighted people also rely on such an assumption to some degree?**

Data validation

To validate that our 60Hz system could reliably record saccadic eye movements, the main sequence (collapsed across subjects and sessions) was compared to that reported by Boghen, et al. (1974, infrared reflection technique, 100Hz), Garbutt, et al. (2001, IR limbus and EOG, 1090Hz), Epelboim, et al. (1997, coil, 976Hz), Wilson, et al. (1993, EOG, 256Hz), and Baloh, et al. (1975, EOG, 200Hz). See Fig. 3a.

Our results were very similar to most published results. Our simulation and Boghen's experiment (Boghen et al., 1974) demonstrated that a low sampling rate affects larger saccades less than smaller saccades (Fig. 3b).

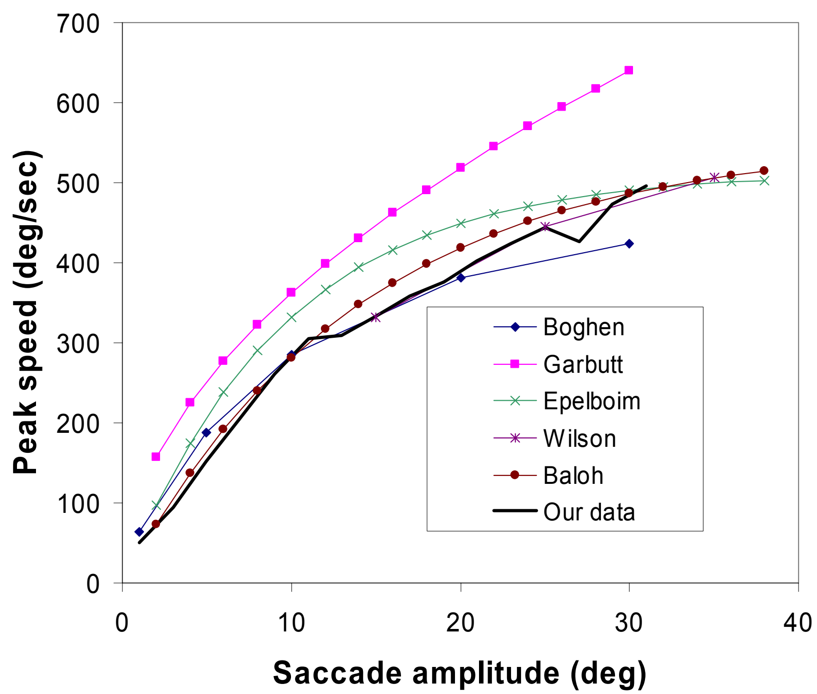

Figure 3a. Comparison of our main-sequence results with other reports in literature.

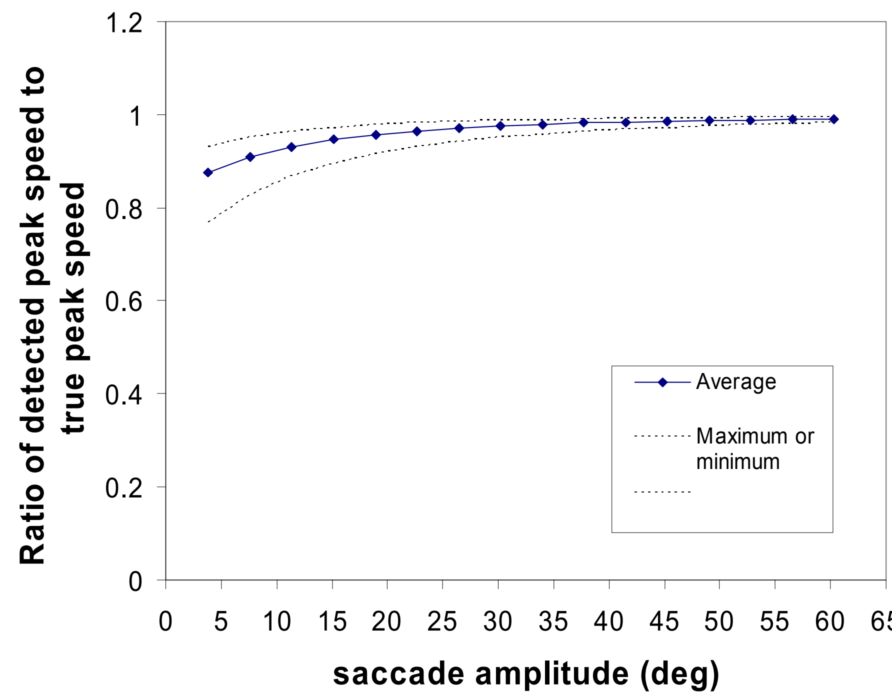

Figure 3b. Ratio of detected peak speed and true peak speed based on simulation. A Gaussian-typed speed profile was simulated.

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