# Saccaidance: Saccade-Aware Pattern Embedding for Gaze Guidance on High-Speed Displays


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**Figure 1: Saccaidance: (a) a saccade-aware guidance cue that stays hidden during fixation and flashes briefly during gaze movements via color-breaking induced by temporal additive color mixing, (b) an example of guidance using the concentric-oval pattern, and (c) an example using the radial-spoke pattern.**


## Abstract

Gaze guidance is essential for directing user attention to specific areas of interest. However, conventional visual cues generate persistent visual noise that hinders concentration during tasks. We propose Saccaidance, a gaze-guidance method that appears only when users move their gaze. Saccaidance employs temporal additive color mixing and 480 Hz high-speed displays to shift the color phase of guidance patterns. This renders the patterns barely visible during fixation and makes them appear transiently when users move their gaze as a color-breaking effect. This intermittent gaze guidance appears only during gaze transitions, providing effective guidance without interfering with focused work or requiring eye-tracking hardware. We conducted experiments with 24 participants under four conditions that involved search tasks: an unmodified baseline, conventional explicit guidance, and our proposed method using oval and radial patterns. The results show that our approach effectively constrains the exploration area while preserving subjective naturalness. We also outline application scenarios of our method, including document highlighting.



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## CCS Concepts

• **Human-centered computing → Mixed / augmented reality**; **Displays and imagers**.

## Keywords

Gaze Guidance, Temporal Additive Color Mixing, Color Vibration, Augmented Reality

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## 1 Introduction

Gaze guidance is essential for directing user attention to specific regions of interest in a natural and efficient manner. Its applications extend beyond capturing attention to improving the effectiveness of advertisements [25], reducing operational errors in user interfaces [6], and facilitating learning in educational contexts [7]. However, gaze guidance faces a fundamental trade-off between guidance effectiveness and minimization of visual obtrusion. Traditional gaze guidance approaches rely on explicit visual annotations, such as arrows [28] and circles [27], overlaid on the original content. While these methods provide reliable guidance, they also create visual obtrusion that disrupts the user workflow.

An ideal gaze-guidance system would minimize visual obtrusion while providing precise and timely guidance. To achieve this, researchers have investigated gaze guidance through saliency manipulation using color and contrast modifications [4, 24, 35], unobtrusive flicker [39] and color vibrations [36]. However, these approaches continuously alter the appearance of the scene and fail to provide guidance only at necessary moments. As an alternative, researchers have proposed eye tracker-based approaches for appropriately timed gaze guidance [5]. Nevertheless, eye trackers present practical challenges, including installation complexity and difficulty in multi-user scenarios because they require individual calibration and raise privacy concerns.

Recent advances in high-refresh-rate display technology have made it possible to create patterns that only become visible when the target or user moves [14, 22, 30]. However, most existing approaches generate visual patterns in response to motion from dynamic objects or body movement, while display systems that respond specifically to eye movement of stationary users remain largely unexplored. Applying these technologies to the user gaze could enable passive gaze guidance by displaying guidance patterns only during gaze transitions, eliminating the need for eye-tracking hardware.

We propose *Saccaidance*, a gaze guidance method that only appears transiently during user gaze movement. Using temporal additive color mixing and 480 Hz high-speed displays, we shift the color phase of the guidance patterns. Although these patterns remain invisible during fixation, they temporarily appear through color-breaking effects during gaze movement. This intermittent system is activated only during intentional gaze movement, providing effective guidance while minimizing interference with the displayed image. To realize the system, we introduce the pattern embedding algorithm for target images, projection frequency optimization for gaze movement perception, and pattern design with contrast characteristics optimized for gaze movement detection. Furthermore, we conducted experiments comparing our approach with a no-guidance baseline and explicit annotation conditions. The results show a significant reduction in task completion time compared to baseline, while maintaining a subjective natural appearance compared to explicit guidance. Our main contributions include:

- proposing Saccaidance, a gaze guidance method that appears transiently only during user gaze movement,
- developing a pattern-embedding algorithm based on temporal additive color mixing for target images, along with projection frequency and contrast characteristics optimized for gaze movement perception,
- demonstrating that our approach preserves subjective naturalness of the displayed image while reducing task completion time, and
- exploring the applications of our method and suggesting directions for future research.

# 2 Related Work

## 2.1 Gaze-Guidance Techniques

Researchers have proposed gaze-guidance techniques for images, videos, graphic interfaces, and mixed reality environments. Conventional gaze-guidance systems mostly employed top-down attention mechanisms, relying on explicit annotations such as arrows [28, 31, 41, 42] and circular and rectangular frames [12, 13, 27, 38, 40] that overlay the target region and provide unambiguous direction. Although these methods offer high reliability, they occlude the primary content and interrupt the visual flow.

To reduce occlusion, researchers have explored bottom-up attention through saliency manipulation, the selective enhancement of visual elements to naturally attract attention [26]. These approaches typically modify either color and contrast properties [4, 18, 24, 35] or employ temporal modulation through flicker effects [5, 20, 34, 39]. While traditional visual guidance provides effective attention direction, they inherently alter the original visual content and remain continuously visible, potentially disrupting the intended viewing experience.

Other approaches introduced selective defocusing [8] or shrinking [33] non-target areas to create a sharpness gradient toward the goal. Such global manipulations degrade peripheral detail and can be disorienting if the user revisits previously blurred content.

## 2.2 Afterimage and Saccade-Contingent Displays

Afterimage effects enable different perceptions depending on motion states [21]. When viewing a light source, even after the perceived light image disappears, observers perceive it as if the light source image continues to exist at the position where it was present immediately before.

Several studies have realized motion-aware displays using the afterimage effect. Saccade-based displays [3] demonstrate that a single vertical column of rapidly blinking light stimuli integrates with afterimages that shift spatially as observers move their gaze, resulting in the perception of two-dimensional images in mid-air. Ikeda et al. [10] proposed temporal light integration to present different images depending on movement direction. Sakaue et al. [29] developed image projection technology that displays different images based on observer velocity. These methods provide different visual experiences according to observer movement or gaze shifts, offering the advantage of being inconspicuous during stationary viewing while providing guidance effects only during motion. MOSion [14, 22] proposes decomposing target regions into mosaic patterns that match the original image through light integration, minimizing image distortion during stationary states while enhancing saliency during motion.

Unlike continuous visual modifications that persistently alter content appearance, motion-contingent approaches preserve the original visual integrity during stationary states. This characteristic represents a significant advantage for achieving effective attention guidance while preserving visual content integrity by activating guidance patterns only when needed.

### 2.3 Information Embedding via Temporal Additive Color Mixing

High-refresh-rate panels enable temporal additive color mixing, wherein sub-frame color components blend into a single hue during normal viewing. This phenomenon occurs when different chromaticities are rapidly alternated above the critical color fusion frequency (CCFF, approximately 25 Hz) [37], causing the visual cortex to respond to imperceptible vibrations while conscious perception cannot detect color changes [11].

Early work utilized imperceptible color vibration for embedding information, including pixel-by-pixel data embedding into LCD images [1, 23] and screen-camera communication via matrix barcode [2, 19]. More recently, researchers have applied temporal additive color mixing for gaze guidance. ChromaGazer [36] and ChromaGazer-HMD [32] exploit rapid alternation between two colors of identical luminance above CCFF to create an intermediate perceptual state between explicit flicker and complete color fusion. This method adjusts color pair amplitude based on MacAdam ellipses [16], achieving gaze guidance without conscious user awareness.

While these flicker-based approaches reduce visual obtrusion, they remain subtly perceptible during slow eye movements and may exhibit residual visibility even during fixation for sensitive observers, which hinders complete invisibility. In contrast, our method leverages saccadic eye movements to achieve guidance patterns that are completely invisible during fixation and visible only during rapid gaze transitions.

## 3 Saccaidance

We describe Saccaidance, a gaze-guidance technique that draws on fundamental properties of human vision. By exploiting temporal additive color mixing together with the eye's persistence of vision, Saccaidance guides user's gaze effectively, yet requires no eye-tracking hardware and thus scales naturally to multi-viewer settings.

Figure 2 shows an overview of the Saccaidance method. The workflow of this method is as follows: (1) prepare the target image and its guidance pattern; (2) embed the pattern and split the colors to decompose them into frame-sequential sub-images; (3) cycle these sub-images on a high-refresh-rate display. When the gaze is stationary, the observer perceives only the target image, but during gaze movement the guidance pattern becomes visible. In this section, we explain the underlying color mixing and after-image phenomena, describe the design of the guidance patterns and their embedding algorithm, and detail the system implementation.

### 3.1 Color Mixing

Digital color has two principal additive schemes: Spatial-color additive mixing (SCM), in which static red-green-blue (RGB) sub-pixels are observed simultaneously, and temporal-color additive mixing (TCM), in which primary colors (normally RGB) are observed in rapid succession and fused in human visual system. Some motion-aware display method [14, 22] use a side effect of TCM called *color-breaking*: when successive frames do not project onto exactly the same location due to the shift of the screen or observer's gaze, edges in the images that should average to single color split into vivid and unintended fringes.

Conventional LCD and OLED displays render each pixel with co-located RGB sub-pixels; their output therefore follows SCM, and color-breaking from persistence of vision does not occur. To induce the phenomenon on commodity OLED hardware, Saccaidance decomposes every source image into four color frames composed of R, G, B, and black and cycles through them at high speed, achieving a TCM presentation.

*Pattern Embedding & Color Split* block in Figure 2 shows how this method splits the colors in each frame. In this method, the color cycle phase of the guidance pattern is shifted to the other part, which yields the vivid edge of the pattern when a color break occurs. The label in the upper-right corner of each image follows the format {image color}_{pattern color}, where R, G, B, and b denote red, green, blue, and black, respectively.

When the eye is fixed, the temporal integration on the retina averages the four frames into one color; therefore, the phase offset is invisible. During gaze movement, however, the retinal image translates between frames at the pattern's boundaries, the mismatched phases failing to integrate, creating high-contrast color fringes that outline the guidance shape. Because the strength of these fringes increases with the chromatic difference between adjacent phases, our decomposition maximizes interphase contrast to ensure reliable edge emergence only during rapid gaze motion while remaining imperceptible during fixation.

### 3.2 Guidance Patterns

Figure 3 shows the gaze-guidance patterns used in Saccaidance: (a) Oval pattern and (b) Radial pattern. Both are centered on the target location and designed to increase the local spatial frequency toward the center. The oval pattern is composed of different sizes of ovals. The spacing between adjacent ovals decreases with proximity to the center, yielding a higher spatial frequency and, consequently, a higher salience near the target. The cue is most readily perceived when the gaze moves toward the target, because the retinal image passes through the oval boundaries orthogonally and maximizes color breaking at the edges. The radial pattern is composed of equiangular lines that extend outward from the target in all directions. As the gaze approaches the center, the distance between lines shrinks, increasing the salience. This pattern is most perceptible when the direction of gaze movement is orthogonal to the target direction. That is, when the retinal motion sweeps across multiple spokes rather than along them. By selecting between these two patterns, the system can accommodate different expected vectors of gaze movement and ensure that color-breaking edges emerge optimally for a given viewing context. We set the maximum separation between the ovals and the spokes to $1^\circ$, the diameter of the central visual field. This ensures that at least one line lies within the central visual field.

### 3.3 Image Modulation

We embed a guidance pattern by running the same high–speed four-color cycle everywhere on the display while introducing a constant phase offset inside the masked region. The instantaneous colors therefore differ across the mask boundary (generating a vivid

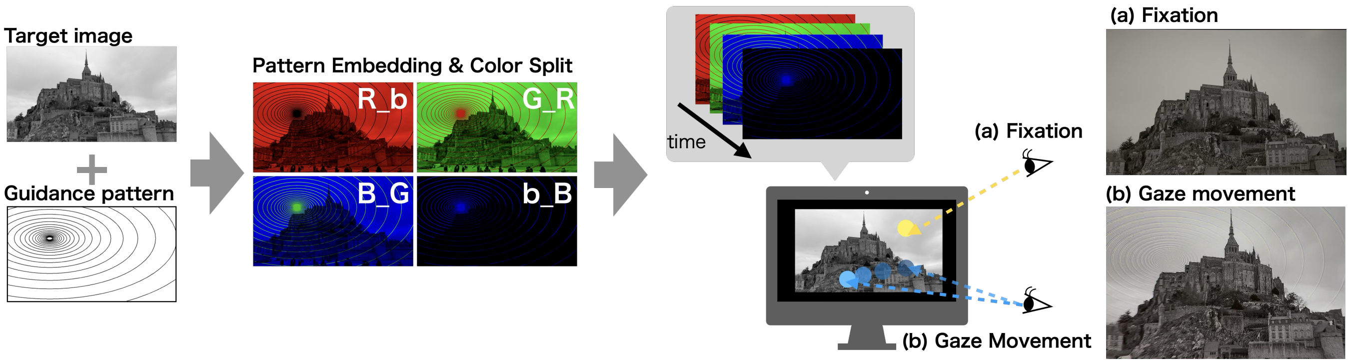


**Figure 2: Overview of Saccaidance: A guidance pattern is generated for the target image and color-split into frame-sequential sub-images. These sub-images are cycled on a high-refresh-rate display. During fixation of the gaze, the viewer sees only the original image, whereas a rapid gaze shift transiently reveals the pattern.**

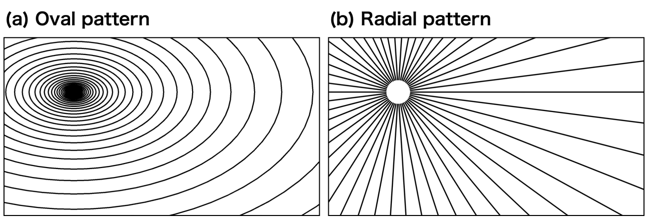


**Figure 3: Guidance patterns: (a) Oval pattern comprises concentric ovals centered on the guidance target. (b) Radial pattern comprises radial spokes that radiate outward from the target.**

*color-breaking* edge during a saccade), yet the time-averaged color is identical in both regions, leaving the pattern invisible during steady fixation.

*Color-cycle model.* Let the cycle of primaries be

$$C = (\text{Red}, \text{Green}, \text{Blue}, \text{Black}), \qquad |C| = 4,$$

indexed by $c_0, c_1, c_2, c_3$. Every display refresh ($\geq$ 480 Hz) shows one color from $C$; after four frames the sequence repeats.

*Phase definition.*

$$\phi(x,y) = \begin{cases} 0, & M(x,y) = 0 \quad \text{(non-pattern)} \\ \Delta\ (=1) & M(x,y) = 1 \quad \text{(pattern)}, \end{cases}$$

where $M$ is a binary mask and $\Delta = 1$ yields a 90° phase offset (e.g. **R_B** in the first frame).

*Frame Synthesis.* For frame index $k \in \{0, 1, 2, 3\}$ the color shown at pixel $(x, y)$ is

$$F_k(x,y) = c_{(k+\phi(x,y)) \bmod 4} \tag{1}$$

A full animation cycle therefore presents

$$\text{non-pattern: } (c_0, c_1, c_2, c_3), \quad \text{pattern: } (c_1, c_2, c_3, c_0),$$

so that each location receives all four primaries

$$\frac{1}{4}\sum_{k=0}^{3} F_k(x,y) = \tfrac{1}{4}(\text{R} + \text{G} + \text{B} + \text{K}),$$

making both regions photometrically equivalent over time.

*Perceptual Effect.* During gaze movement, the retinal image shifts rapidly; because the two regions are in different phases of the cycle, adjacent pixels momentarily display opponent-hue pairs (e.g. **Red_Blue**), producing a high-contrast color-breaking contour. Under fixation, temporal integration removes this mismatch and the embedded pattern remains concealed.

*Implementation steps.* This phase-shift modulation embeds salient saccadic cues in arbitrary images without degrading their apparent quality during normal viewing. The following shows the procedure for embedding patterns into each image:

(1) **Prepare** the binary mask $M$ from the desired guidance pattern.
(2) **Generate** four sub-frames $F_0, \ldots, F_3$ with the rule above.
(3) **Display** the sub-frames in a cyclic loop.

# 4 Implementation

To confirm that the method described above can be realized with commodity hardware, we built a proof-of-concept prototype that drives guidance-embedded imagery in real time at 480 Hz. The prototype demonstrates that the color phase shift technique remains imperceptible during fixation, yet becomes visible during rapid eye movement.

*Image Construction.* When guiding the gaze in our system, the designer first selects the target image to be presented to the observers and specifies a point of interest (POI) toward which the gaze of the viewers should be directed. Our system then constructs a binary modulation pattern that steers the gaze toward the POI. To this end, the target image is decomposed into four subimages.

*Graphics.* We employ the Vulkan SDK as the graphics API because its explicit swap-chain management enables seamless image switching at a stable refresh rate. The four sub-images are preloaded as GPU textures and presented sequentially, one per video frame.

*Hardware.* All experiments are performed on a Sony INZONE M10S [1] QHD OLED display operating at 480 Hz. A higher refresh rate suppresses visible flicker but shortens the duration of each frame, demanding faster saccade eye movements, and thereby diminishing the salience of the guidance cues. In contrast, a lower refresh rate increases the likelihood of flicker perception. Given that the critical flicker fusion frequency (CFF) for a two-frame stimulus is approximately 50–90 Hz [17], we target a four-frame sequence whose period satisfies $1/(4f) < 1/\text{CFF}$, which implies $f > 360$ Hz. We therefore adopt 480 Hz, a value that is safely above this threshold. A preliminary experiment confirmed that participants did not perceive flicker under this setting.

# 5 User Study

To evaluate whether Saccaidance (i) effectively guides gaze and (ii) minimally intrudes on perception through a two-stage study: a parameter-search pilot followed by a controlled main experiment.

## 5.1 Preliminary Experiment

We conducted a brief pilot study (N=4; 2 female, 2 male; ages 22–34, $M = 26$) to select display parameters that remain imperceptible during fixation yet become visible during saccades.

*5.1.1 Design.* We used a within-subjects $4 \times 3$ factorial design manipulating line thickness (2, 4, 6, 8 px; $\approx 3'$, $6'$, $9'$, $12'$) and display (color-cycle) frequency (240, 360, 480 Hz). Each parameter combination was tested at three target separations (8°, 13.5°, 19°).

*5.1.2 Stimuli.* Two static white circular targets (10 px diameter; $\approx 12'$) were superimposed on the visual-search image used in the main experiment. An oval line pattern, centered on the display, was embedded using the proposed method at the specified frequency and thickness.

*5.1.3 Procedure and Scoring.* For each parameter combination, participants alternated their gaze between the two targets several times and rated pattern visibility at each separation on a 0–2 scale (0 = invisible, 1 = sometimes visible, 2 = visible). The three ratings were summed to yield a composite visibility score per combination (range: 0–6). Our selection criterion was a composite score of 3, corresponding to invisibility at 8°, occasional visibility at 13.5°, and reliable visibility at 19°.

*5.1.4 Outcome.* Table 1 reports the mean composite visibility scores. The combination of 6 px lines and a 480 Hz color-cycle frequency most closely matched the target visibility profile; two of the four participants produced a score of 4 under this condition. At 240 and 360 Hz, mean scores exceeded 4, indicating excessive visibility and obtrusion. Two participants reported visibility at all separations in these lower-frequency conditions, suggesting that the pattern was perceived as flicker.

Based on these results, the parameter combination of 6 px ($\approx 9'$) lines and 480 Hz produced the clearest transient edges during saccades without detectable flicker during fixation. We therefore fixed these parameters for the subsequent main experiment.

[1] https://www.sony.com/en-sn/gaming-gear/products/inzone-m10s

**Table 1: Visibility Evaluation Results**

| | Color-cycle Frequency | | |
|---|---|---|---|
| Line Thickness | 240 | 360 | 480 |
| 2 | 4.75 | 4 | 1.25 |
| 4 | 5.75 | 4 | 2 |
| 6 | 6 | 5.75 | 3 |
| 8 | 5.75 | 5.75 | 4.25 |

## 5.2 Main Experiment

The main study employed a within-participants design with four display conditions. The conditions are as follows:

**Baseline:** Unmodified original stimulus without guidance
**Conventional:** Static black line around target
**Proposed_Oval:** *Saccaidance* with concentric ovals
**Proposed_Radial:** *Saccaidance* with radial spokes

Two filler trials were included in each session: one *long-distance* and one *misleading-cue* (guidance directed to a distractor),to reduce predictability and prevent participants from memorizing the target location. Data from these were excluded from inferential analyses.

*5.2.1 Hypotheses.* We formulated the following three hypotheses:

- **H1:** Both Saccaidance variants reduce visual search task completion time and alter gaze trajectories relative to the unmodified Baseline.
- **H2:** Saccaidance is not rated as less natural or more obtrusive than conventional method.
- **H3:** Saccaidance yields lower visual distraction than conventional static highlighting.

*5.2.2 Task.* Stimuli comprised $18 \times 43$ grids of the digit “5” with a single embedded “2”. Each trial followed the following sequence:
**1. Fixing gaze on screen:** a white cross on a black background (3 s) to stabilize gaze.
**2. Search stimulus:** the grid appears under one of four guidance conditions. Participants press the spacebar while fixating the “2”.
**3. Blank gray screen:** prevents afterimages of the retina before the next trial.

Five trials constituted a set; participants completed four sets (≈20 min total) with a 1–2 min rest between sets.

*5.2.3 Participants.* 24 participants (15 males, 8 females, and 1 who preferred not to disclose their gender; mean age = 23.4 years) with normal or corrected-to-normal vision were recruited from the university community and received around 10 dollars compensation.

This experimental protocol was approved by the Human Subjects Research Ethics Review Committee of Institute of Science Tokyo.

*5.2.4 Apparatus.* Figure 4 (Left) shows the apparatus of the user study. The participants were seated with their chin on a rest to stabilize the head position, ensuring that their eyes were level with the center of a 27-inch display (INZONE M10S, Sony) positioned 530 mm away. The displays were set to use the sRGB color space.

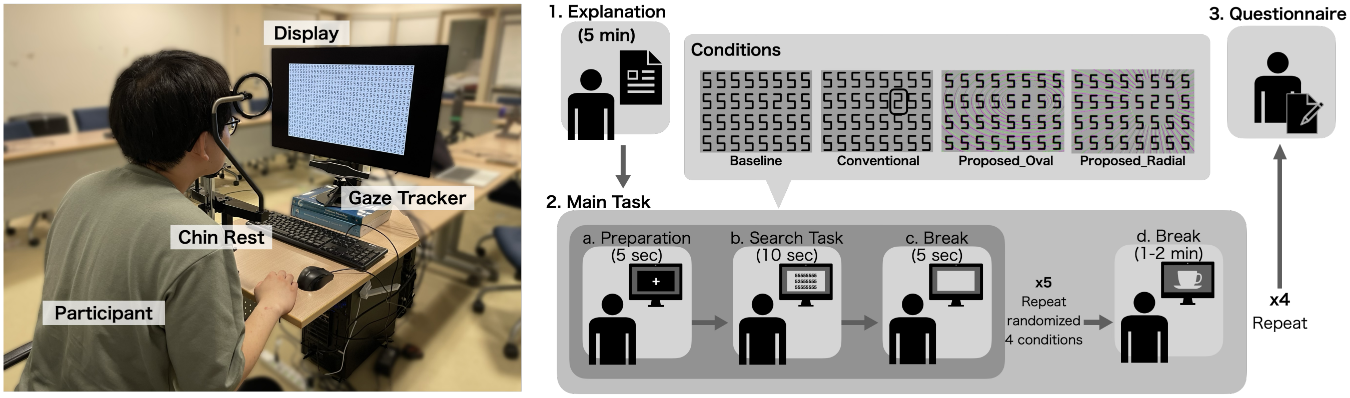


**Figure 4: User study overview: (Left) Apparatus for the user study. (Right) Procedure of the User study.**

*5.2.5 Procedure.* Figure 4 (Right) illustrates the experimental procedure followed in the user study.

**1. Explanation:**We provide a detailed explanation of the experiment and confirm the user interface and operations used during the task.

**2. Main Task:** The participant places their head on a chin rest in front of the display, and we perform calibration for the eye-tracking system. After calibration, the participant performs the visual search task. One task consists of the following steps (a)–(c).

(a) A white fixation cross appears on a black screen for 3 s. The participant is instructed to maintain gaze on the cross.

(b) The participant performs a visual search task in which they must locate a single "2" among an array of "5"s. Once they find the "2," they press the space bar while keeping their gaze on it.

(c) A gray screen is displayed as a short break. Pressing the space bar returns the task to step (a).

One repetition of (a)–(c) constitutes a *trial*. After five trials, the participant removes their head from the chin rest and takes a 1–2 min rest. This sequence is repeated four times, counterbalancing the order of condition, answer location, and guidance method.

**3. Questionnaire:** The participant performs the task again under each guidance condition and then completes a questionnaire. The presentation order of the conditions is counter-balanced.

Within the five trials of a single session (step 2), four search tasks employ the intended guidance for each condition, and one task deliberately guides the participant to an incorrect location (*misguidance*). Among the first four search tasks, one displays the target at a greater eccentricity (*long-distance search*). The presentation order is designed and randomized so that normal guidance, long-distance search, and misguidance trials appear with equal frequency.

*5.2.6 Measurements.* For quantitative evaluation, we measured task completion time and gaze movements recorded by the eye-tracking device (GP3, Gazepoint).

For qualitative evaluation, we administered a questionnaire. Participants rated naturalness and obtrusion on a Likert scale and provided open-ended comments on each condition. Following prior work [15], we defined the Likert scales for naturalness and obtrusion as follows.

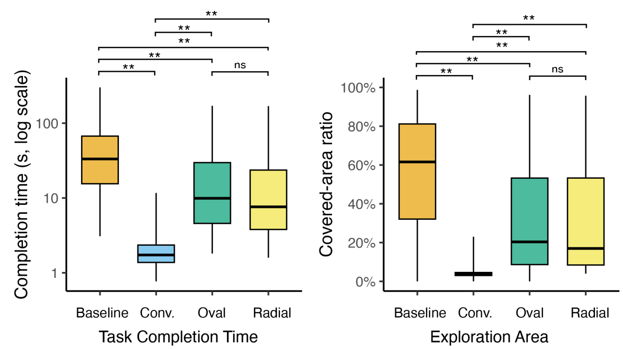


**Figure 5: Results of (Left) task completion time. (Right) proportion of the image explored during the task.**

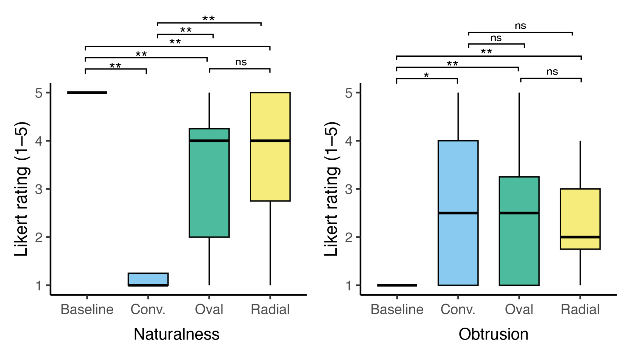


**Figure 6: Results of a questionnaire on the four display conditions**

**Naturalness:** The extent to which the image appeared unprocessed (1: very unnatural – 5: very natural).
**Obtrusion:** The degree to which the image stood out undesirably (1: not at all obtrusive – 5: very obtrusive).

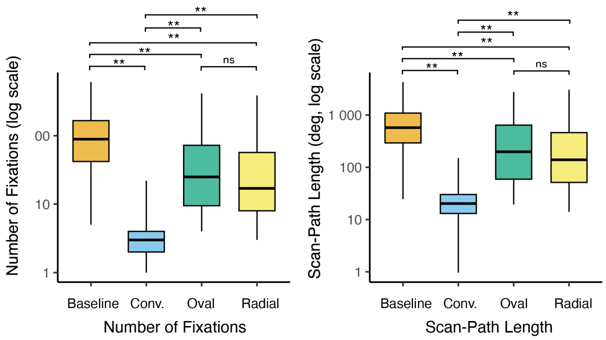


**Figure 7: Results of (Left) number of fixations (Right)scan-path length.**

## 6 Results

We evaluated the experiment from three perspectives: (i) task completion time (time to press key after finding the target), (ii) proportion of the image explored by the fixations during task, and (iii) scores from the user questionnaire. Throughout this section, we refer to the four display conditions as Baseline, Conventional, Oval, and Radial. Unless otherwise stated, $r$ denotes Cohen's $r$.

### 6.1 Task Completion Time

The task completion time was recorded based on participants' responses. Figure 5 shows the task completion times for the four display conditions. As a result of conducting Friedman test, the main effect of the display conditions on the completion time was significant ($\chi^2 = 52.250$, $p < 0.01$). Since the main effect is significant, the Wilcoxon signed-rank test was repeated under the Holm method as a sub-test. As a result, the task completion time of Baseline was significantly higher than Oval ($p < 0.01$, $r = 0.71$), Radial ($p < 0.01$, $r = 0.54$), and Conventional ($p < 0.01$, $r = 0.87$). Conventional was significantly lower than Oval ($p < 0.01$, $r = 0.87$) and Radial ($p < 0.01$, $r = 0.87$). However, no significant differences were observed between Oval and Radial ($p = 0.94$, $r = 0.02$).

### 6.2 Proportion of Explored Area

We calculated the proportion of the image explored by the gaze using the eye-tracking data. We considered the area within the central vision field (within 5 degrees of visual angle) during fixation as the exploration area. We use the gaze data which are classified as fixation by Gazepoint Analysis software. The total exploration area was divided by the total image area to obtain the proportion. Figure 5 shows the results. As a result of conducting the Friedman test, the main effect of the display conditions on the proportion of explored area was significant ($\chi^2 = 46.85$, $p < .001$). Since the main effect was significant, the Wilcoxon signed-rank test was repeated under the Holm method as a sub-test. As a result, the ratio of exploration area of Baseline was significantly higher than Conventional ($p < 0.01$, $r = 0.875$), Oval ($p < 0.01$, $r = 0.642$), and Radial ($p < 0.01$, $r = 0.63$). Conventional was significantly lower than Oval ($p < 0.01$, $r = 0.875$) and Radial ($p < 0.01$, $r = 0.869$). However, no significant differences were observed between Oval and Radial ($p = 0.64$, $r = 0.163$).

### 6.3 Number of Fixations

We calculated the total number of fixations during the task using the eye-tracking data. Specifically, we used gaze data classified as fixations by the Gazepoint Analysis software. Figure 7 shows the results. As a result of conducting the Friedman test, the main effect of the display conditions on the number of fixations was significant ($\chi^2 = 50.19$, $p < .001$). Since the main effect was significant, the Wilcoxon signed-rank test was repeated under the Holm method as a sub-test. As a result, number of fixations of Baseline was significantly higher than Conventional ($p < 0.01$, $r = 0.875$), Oval ($p < 0.01$, $r = 0.642$), and Radial ($p < 0.01$, $r = 0.706$). Conventional was significantly lower than Oval ($p < 0.01$, $r = 0.875$) and Radial ($p < 0.01$, $r = 0.869$). However, no significant differences were observed between Oval and Radial ($p = 0.22$, $r = 0.257$).

### 6.4 Scan-path Length

We calculated the total scan-path length during the task using the eye-tracking data. Specifically, we used gaze data classified as fixations by the Gazepoint Analysis software and computed the visual angle between contiguous fixations. Figure 7 shows the results. As a result of conducting the Friedman test, the main effect of the display conditions on the scan-path length was significant ($\chi^2 = 47.85$, $p < .001$). Since the main effect was significant, the Wilcoxon signed-rank test was repeated under the Holm method as a sub-test. As a result, the scan-path length of Baseline was significantly higher than Conventional ($p < 0.01$, $r = 0.875$), Oval ($p < 0.01$, $r = 0.636$), and Radial ($p < 0.01$, $r = 0.706$). Conventional was significantly lower than Oval ($p < 0.01$, $r = 0.875$) and Radial ($p < 0.01$, $r = 0.857$). However, no significant differences were observed between Oval and Radial ($p = 0.14$, $r = 0.303$).

### 6.5 Number of Errors

Under normal conditions, no errors are recorded. In contrast, in Conventional with a misleading cue, four participants fixed on the distractor, misidentified it as the target, and pressed the button. No errors were observed in any of the other misleading-cue conditions.

### 6.6 Qualitative Result

Figure 6 shows the questionnaire results for naturalness and obtrusion, respectively. The details of results are as follows:

**Naturalness:** A Friedman test revealed a significant effect of Group on Value ($\chi^2(3)$=41.10, p < 0.001). Since the main effect was significant, the Wilcoxon signed-rank test was repeated under the Holm method as a sub-test. The result showed the score of Baseline was significantly higher than Conventional (p < 0.01, r = 0.877), Oval (p < 0.01, Cohenf's r = 0.769), and Radial (p < 0.01, r = 0.743). The score of Conventional was significantly lower than Oval (p < 0.01, r = 0.689) and Radial (p < 0.01, r = 0.729). There was no significant difference between Oval and Radial (p = 0.153, r = 0.291)

**Obtrusion:** A Friedman test revealed a significant effect of Group on Value ($\chi^2(3)$=20.46, p < 0.01). Since the main effect was significant, the Wilcoxon signed-rank test was repeated under the Holm method as a sub-test. The result showed that the score of Baseline was significantly lower than Conventional (p = 0.03 < 0.05, r = 0.612), Oval (p < 0.01, r = 0.733), and Radial (p < 0.01, r = 0.71). There were no significant difference between Conventional and Oval (p = 0.875, r = 0.0322), Conventional and Radial (p = 0.620, r = 0.101), and Oval and Radial (p = 0.470, r = 0.148).

The optional free-response field yielded rich remarks on how each stimulus was perceived:

**Conventional condition:** Several participants reported that the rectangular overlay drew their attention immediately. For example, "I looked at the boxed region first because it stood out" (P3, P21). Others found the cue disruptive: "The visual incongruity was so strong that I couldn't focus on anything else" (P22).

**Oval and radial condition:** In oval condition, fourteen participants explicitly recognized "oval" or "circles". As for Radial condition, thirteen participants identified "radiating" or "concentric" lines, and one reported simply seeing "lines." Another remarked that the pattern created "…a sense of depth" (P24).

Three participants stated that they did not notice any pattern at first but became aware of it in later sessions; for example, "I didn't notice the colorful lines and circles at first, but from Session 2 they highlighted the number '2' without distracting me" (P4).

Overall, the free-text comments confirm that Saccaidance's oval and radial cues were initially unobtrusive yet became informative once detected, contrasting with the conventional cue's overt but intrusive character.

## 6.7 Discussion

*H1: Both Saccaidance conditions reduce visual search task completion time and alter gaze trajectories relative to the unmodified Baseline.* Participants found the target significantly faster with both the Oval and Radial Saccaidance variants than with Baseline (Figure 5 (left); pairwise comparisons, $p < .001$ for both). At the same time, the proportion of the image that participants inspected was smaller for each condition, indicating a more efficient scan path. Taken together, these results suggest that Saccaidance steers eye movements and reduces the number of fixations needed to locate the target, which in turn lowers overall search time. These results support H1.

*H2: Saccaidance is not rated as less natural or more obtrusive than conventional method.* The questionnaire analysis revealed that participants perceived the Saccaidance conditions as more natural than the conventional method, a finding corroborated by the statistical tests conducted on the Likert-scale responses. However, no significant differences were detected in obtrusion between the Saccaidance approach and the conventional approach. Therefore, H2 is partially supported. To achieve a less obtrusive display, it will be necessary to adjust parameters such as frequency and pattern thickness in accordance with the content presented.

*H3: Saccaidance yields lower visual distraction than conventional static highlighting.* In Conventional, four participants made incorrect responses to the misleading cue. They fixed on the distractor, misidentified it as the target, and pressed the response button. In contrast, no errors were observed under the Saccaidance condition. This suggests that the conventional method induced mistakes due to visual distraction. On the other hand, some participants reported that they did not initially notice the guidance pattern in the proposed method. This indicates that the distraction caused by the proposed method was not strongly perceived. Taken together, these findings support H3.

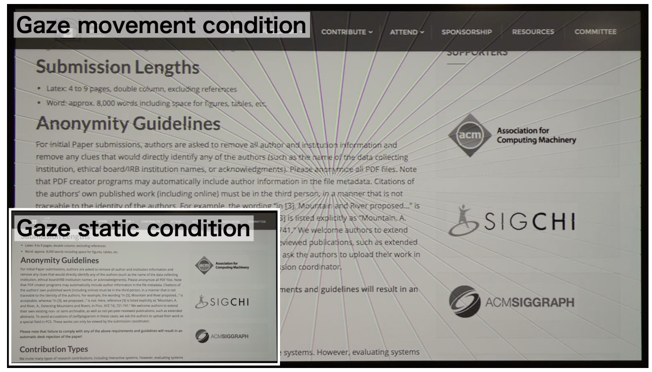


**Figure 8: Document highlighting application: Main panel: screen appearance while the user's gaze is moving; the guidance pattern becomes visible and directs attention toward key terms. Inset (lower left): view during fixation, where the pattern remains invisible and the page looks unaltered.**

# 7 Discussion and Future Work

## 7.1 Application Scenarios

The proposed method enables users to regulate cue focusing through their own eye movements, ensuring that guidance does not interrupt the primary task and can remain unnoticed when desired. Unlike conventional highlighting systems that remain constantly visible and create visual noise, this approach implements guidance cues that appear only during natural eye movements and disappear upon reaching the target, creating a seamless and non-intrusive interaction paradigm. While the method is primarily intended for gaze guidance within advertisements, this could also be applied to emphasizing specific words or passages within text and to guiding the reading flow in picture books and comic.

Figure 8 illustrates a document-highlighting application for technical and educational materials on web and other digital platforms. Salient terms are highlighted via configurable criteria such as keyword extraction, importance scoring, user preferences. In the example, a brief saccade directs gaze to "Please anonymize all PDF files." Sensitivity to eye-movement velocity enables adaptive behavior: during slow, deliberate reading the guidance remains inactive; during rapid skimming across paragraphs or sections it activates to draw attention to highlighted content. Readers can thus shift between careful analysis and targeted inspection by modulating natural eye movements.

There is a practical trade-off between highlight conspicuity and obtrusion. Compared with explicit bounding boxes, which reduce time-to-notice but may occlude content, our method prioritizes low obtrusion and content preservation, at the cost of somewhat slower attentional capture. This design is appropriate when minimal disruption is critical, such as in scenarios where multiple people share a single display (e.g., public displays, exhibition and education settings, and collaborative viewing).

## 7.2 Conditions for Guidance Visibility

We hypothesize that the guidance is perceived primarily during saccades. Based on calculations from the preliminary user study, guidance becomes reliably visible when saccadic peak velocity exceeds approximately 330–680°/s. We did not measure saccade duration in this experiment, so the precise operating point remains uncertain; to obtain tighter bounds we plan to verify perceptual changes while recording saccade onset/offset and duration with a high-speed eye tracker. By contrast, microsaccades (~10°/s) and smooth pursuit (~50°/s) fall well below this range, so the guidance cues should seldom appear and would be scarcely noticeable during such slow eye movements grained inspection. Regarding saccadic suppression, our hypothesis is that frames presented during the saccade are effectively excluded from the temporal integration window that would otherwise mix adjacent frames for color perception; as a result, the cue is not averaged away and becomes visible. We will explicitly test this mechanism in future studies.

## 7.3 Technical Limitations of Color-Phase-Shift Modulation

Color-phase-shift modulation relies on decomposing per-channel luminance, which introduces several technical constraints. Very dark or fully black regions offer insufficient dynamic range for reliable embedding, as the color vibration mechanism requires adequate luminance levels to generate perceptible phase differences. While previous work by Hattori et al. [9] has demonstrated that practical color vibrations can be generated for most real-world colors, regions with extremely low luminance values may require color-shifting techniques to achieve effective guidance patterns.

Display-specific gamma characteristics present another technical challenge that affects the linearity required for color vibration generation. Non-linear gamma curves can distort the intended color phase relationships, potentially compromising the effectiveness of the guidance mechanism. However, this limitation can be addressed by performing degamma correction and generating patterns in linear color space, ensuring that the temporal additive color mixing operates as intended across different display technologies.

The current implementation is optimized for grayscale imagery, and extending the method to full-color images and video sequences presents additional complexity. The threshold parameters for full-color applications remain unexplored, though preliminary investigations by Hattori et al. [9] provide a foundation for future exploration. The interaction between existing image colors and the embedded guidance patterns requires careful consideration to maintain both the original image quality and the effectiveness of the guidance mechanism.

## 7.4 Evaluation Limitations

Our evaluation used head-fixed young adults in a controlled laboratory, which may not reflect real-world use. Transitioning to free-head viewing introduces additional complexity, coupled eye and head dynamics. In natural environments, the composite motion of gaze and head can alter the conditions when guidance patterns become visible, potentially affecting effectiveness. Quantifying these effects and identifying parameters robust to free-head viewing are important for deployment.

The participants were consisted of young adults with normal or corrected to normal vision, which limits generalizability. Specialized parameter adjustments or alternative approaches would be needed for individuals with color vision deficiencies. Additionally, age-related changes in color perception may affect the threshold for color vibration detection. The critical flicker fusion frequency and color discrimination abilities both change with age, which could influence the optimal refresh rates and color phase differences required for effective guidance. Comprehensive user studies incorporating diverse populations, including different age groups, individuals with color vision deficiencies would provide valuable insights into the method's broader applicability.

## 7.5 Scope and Applicability Constraints

The current system's reliance on specific color combinations limits its applicability to scenarios where color selection is constrained. In natural scenes where the original color palette cannot be modified, color-shifting techniques may be necessary to create suitable conditions for pattern embedding. This constraint is particularly relevant for applications involving photographic content or brand-specific color schemes where maintaining color fidelity is paramount.

The method's effectiveness is also dependent on the spatial and temporal characteristics of the content. Rapidly changing scenes with high spatial frequency may interfere with the guidance pattern visibility, while static content provides optimal conditions for the color-breaking effect. The system's performance with dynamic content, such as video sequences or interactive applications, requires further investigation to establish appropriate adaptation strategies.

## 7.6 Hardware and Environmental Dependencies

The effectiveness of Saccaidance is tied to high-refresh-rate image presentation. Based on our preliminary results, a refresh rate of at least 480 Hz is required for reliable performance, which currently confines deployment to ≥ 480 Hz displays or projection systems.

The interplay among refresh rate, cue visibility, and perceived flicker must be carefully tuned for different display technologies and viewing conditions. Environmental factors such as ambient lighting conditions and viewing distance may also influence the system's performance. The color vibration mechanism's sensitivity to these factors has not been thoroughly investigated, and optimal parameter settings may need to be adjusted based on the specific deployment environment.

# 8 Conclusion

We introduced *Saccaidance*, a saccade–aware gaze-guidance method that embeds phase-shifted patterns in a four-frame color cycle on 480 Hz OLED displays. By exploiting temporal additive color mixing, the guidance cue is virtually invisible during fixation yet emerges transiently as vivid color-breaking contours only while the eye is in flight, thereby directing attention without persistent visual clutter and without any eye-tracking hardware requirements.

Our paper shows that *Saccaidance* unlocks an under-explored design space: ephemeral, gaze-contingent cues that respect the integrity of on-screen content while still steering attention. We believe this approach can inform next-generation UI components, AR/VR overlays, and public displays where attention must be guided subtly, scalably, and without specialized hardware.

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