Peripheral Notifications in Large Displays: Effects of Feature Combination and Task Interference

Aristides Mairena
Department of Computer Science
University of Saskatchewan
Saskatoon, Canada
aristides.mairena@usask.ca

Carl Gutwin
Department of Computer Science
University of Saskatchewan
Saskatoon, Canada
gutwin@cs.usask.ca

Andy Cockburn
Department of Computer Science
University of Canterbury
Christchurch, New Zealand
andy@cosc.canterbury.ac.nz

ABSTRACT

Visual notifications are integral to interactive computing systems. With large displays, however, much of the content is in the user's visual periphery, where human capacity to notice visual effects is diminished. One design strategy for enhancing noticeability is to combine visual features, such as motion and colour. Yet little is known about how feature combinations affect noticeability across the visual field, or about how peripheral noticeability changes when a user's primary task involves the same visual features as the notification. We addressed these questions by conducting two studies. Results of the first study showed that noticeability of feature combinations were approximately equal to the better of the individual features. Results of the second study suggest that there can be interference between the features of primary tasks and the visual features in the notifications. Our findings contribute to a better understanding of how visual features operate when used as peripheral notifications.

CCS CONCEPTS

• **Human-centered computing → Information visualization**;

KEYWORDS

Notification; peripheral vision; popout; visualization.

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1 INTRODUCTION

Visual notifications play an important role in interactive computing systems by providing rapid availability to information in an efficient and effective manner. While notifications may vary in importance to users, they are found to be valuable in keeping users aware of information while they attend to a primary task [29]. These visual notifications are employed in a variety of desktop applications including instant messaging systems, news, weather, sports, and status programs.

The design of visual notifications entails two main considerations: first, visual notifications should be noticeable, as they usually aim to attract a user's attention to a location away from their main task; second, their noticeability has to be moderated to prevent user distraction and annoyance. Overly-distracting notifications have been shown to induce higher levels of stress [27], mistakes [5], and productivity loss [14]. The design of visual notifications, therefore, is a task that requires careful attention.

Although notifications have been around for a long time on standard desktop environments, new computing environments such as large screens add new factors that have to be taken into account when designing notifications. When people work on large screens (e.g., multi-monitor setups, curved widescreen panels, wall displays) much of the display content is in the user's visual periphery, and notifications typically appear on the edges of the display. Previous work has shown that visual features lose some of their noticeability in peripheral vision; in particular, the phenomenon of "popout" diminishes as the stimulus moves farther from central vision [19]. Therefore, on large displays, notifications that appear on the edges of the display may be difficult to see and notice. In order to better design visual notifications for large display environments, we need to better understand how we can control the visual salience of notifications in the peripheral vision.

While previous work provides a foundation on how we perceive stimuli in our peripheral vision, there are two important questions that need to be investigated. First, can noticeability be improved by combining visual features (e.g., can we overcome reduced sensitivity in peripheral vision by combining different features, such as colour + motion?). Adding visual features is a common design strategy, but research in perceptual psychology suggests that the different perceptual pathways for different features may not be independent [4, 33], and little is known about how combinations of features affect noticeability. Second, as most notifications are employed while a user focuses on a primary task, we need to understand how (and whether) peripheral noticeability changes when a user is working on a task comprised of different visual effects.

To answer these two questions, we carried out two studies. First, to investigate the effects of combining visual features across the human visual field, we conducted a laboratory study that tested people's ability to detect popout targets that used combinations of three visual variables. Using the results from Gutwin *et al.* [19], we selected color, shape, and motion as our visual variables, as they provide varied levels of noticeability. Participants were shown a visual target for 240ms, at different intensity levels (i.e., the difference between the target and distractors in terms of the visual variable), in a triple-monitor setup that allowed us to present the targets up to 62° from the center in both directions.

Our second study focused on investigating peripheral noticeability and distraction when a user is working on a primary task that involves visual effects that are also used in the notification. We asked participants to detect a subset of the popout targets presented in study 1 while they played a modified version of the arcade game Snake [1] (which uses motion extensively).

Our two studies provide several new findings about people's ability to perceive stimuli in the visual periphery:

- Combinations of visual variables (e.g., any combination of colour, shape, and motion) were always approximately equal to the better of the individual features.
- There was interference between the visual features of the primary task and notification (the salience of motion in peripheral notifications was diminished when motion was part of the primary task).
- Primary task performance indicates participants were distracted by the visual effect of motion.

Our studies contribute to a better understanding of how visual features operate when used as peripheral notifications. We provide new insights, both in terms of combining features, and interactions with primary tasks. Designers can use our results to improve their design approaches for achieving noticeability when designing for large information spaces.

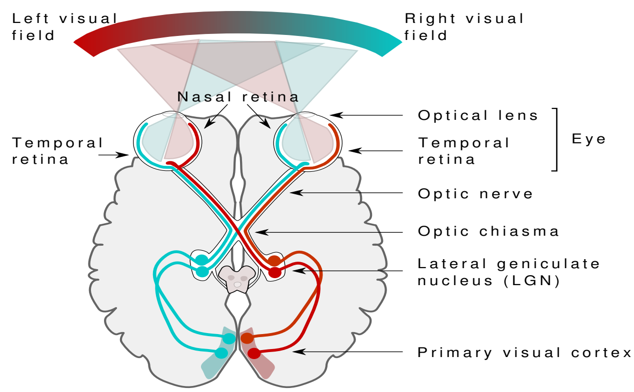

Figure 1: A simplified schema of the human visual pathway. From Nieto [32].

2 RELATED WORK

Neurology of Vision

Human visual processing begins in the retina when rod and cone photoreceptor cells react to light energy [45]. Color-sensitive cone cells are predominantly located in the densely packed central foveal region of the eye [49], whereas rod cells are distributed more broadly across the retina and provide sensitivity to low light levels and assist in detection of shape and movement. Rod cells contain only one pigment, making them poor for color vision.

The eye transmits information about the world to the brain through the fibers of the optic nerve along at least three distinct pathways (Figure 1). The pathways arise from neurons in the retina called magnocellular (M) cells, parvocellular (P) cells, and koniocellular (K) cells. These neurons respond to different visual stimuli. For example, M cells specialize in detecting the location, speed, and direction of moving objects [23]. M cells have a high contrast sensitivity, and are essential for performing visual search and detecting changes in luminance [11]. P cells are sensitive to color and are also involved in the analysis of shape and size. K cells also respond to color and provide various other functions relating to spatial and temporal vision [52].

Cells in the primary visual cortex contribute to detection of visual stimuli, such as orientation and motion [8, 33, 34]. Previous research has considered the independence of these mechanisms by studying additive saliency effects of orientation and motion contrast, with results suggesting that mechanisms are not completely independent [33].

Visual Attention

There are various theories and computational models of selective attention, but in general they agree that attention operates by successively selecting "features" of the incoming sensory data for further processing [38]. Early work suggests a two-stage process: first, a fast pre-attentive stage in which more-salient items draw attention [51]; second, a slower stage that is driven by current tasks and goals [24, 37, 46]. Within this model, the conjunction of basic features (such as color and orientation) stems from "binding" features together (known as Feature Integration Theory [46]).

The Guided Search Theory also follows the two-stage architecture, but proposes that attention can be biased toward targets of interests (e.g., a user looking for a red circle) by encoding items of user interest [50]: for example, assigning a higher weight to the red color.

New evidence that attention not only depends on simple features but also on the scene's structure has raised challenges for the two-stage model [38, 40, 51]. A new proposed model consists of three processes: current goals, selection history and physical salience (bottom-up attention) [3]. This work argues that there is bias to prioritize items that have been previously selected, which may differ from current goals, and as such, selection history and goal-driven selection should be viewed as different categories in visual attention.

In order to understand the capacity of human vision, we must understand the limitations of peripheral vision [39]. Peripheral vision is often used unconsciously, and helps guide our eye movements to a target, playing an important role in orientation and navigation. Peripheral vision, being much larger than foveal vision, is more likely to contain a target. However, people's capabilities in peripheral vision are substantially worse than in foveal vision – there is a sharp decline in people's ability to perceive information as visual angle increases (e.g., only one tenth of visual detail is detectable at an angle greater than 10° from central vision [43]). Previous research also suggests that peripheral vision constrains visual search performance [39]. A notable exception, however, is that our ability to detect motion remains relatively constant across the visual field [19, 47].

Notifications and Distraction

In large-scale safety-critical systems, such as control rooms and aircraft cockpits, alarms tend to propagate rapidly [47]. Previous research has found that an excess of visual alerts reduces human processing capability due to disturbance and distraction [17, 41, 48].

Many consumer-grade user interfaces such as email inboxes and system settings also employ alerts, often away from a user's central vision. Humans, however, are not well adapted for continuous monitoring tasks, and can fail to notice obvious changes due to Change Blindness and Inattention Blindness [6, 15]. Change Blindness is often due to visual disruption [15, 35], and is more likely to occur when change occurs on a stimulus that the user is not focusing on [47]. Inattention Blindness refers to a failure to perceive a stimulus that is in plain sight [42]. Failure to notice stimuli is particularly prevalent when performing repetitive and monotonous tasks.

Previous research on notification design has proposed a proportionality between stimuli salience and the importance of the content [18, 30, 36]. Matthews *et al.* suggested five categories of notification salience: ignore, change blind, make aware, interrupt, and demand attention [28].

Avoiding distraction and irritation during notifications is a difficult design task. Ware studied the use of moving icons for notification, finding it effective and less irritating than other effects such as blinking and flashing [48].

Despite extensive prior research on vision science, it remains unclear how to effectively draw the user's attention to items farther away from central vision (as is particularly important with larger displays). In the following studies, we set out to determine the effects of various combinations of popout effects as an effective way to draw attention in interactive systems.

3 STUDY METHODS

User interface notifications are designed to be visible for extended periods of time (e.g., Windows 10 notifications can be customized to be visible for 5 seconds up to 5 minutes), giving a user an ample amount of time to interact with a notification. The most effective notifications, however, have to be designed to be immediately noticeable.

The following two studies examined *instantaneous peripheral noticeability* of different popout visual effects, and their distraction effects in an applied setting. Our first study was designed to determine the effects of combining visual features on peripheral noticeability. The goal of our second study was to measure the peripheral noticeability of popout effects while participants focused on a primary task involving motion. We also used performance in the primary task as a way of measuring the distraction caused by the different popout effects.

STUDY 1: ADDITIVE EFFECTS

In a previous study, Gutwin, Cockburn and Coveney [19] determined the effects of visual angle and stimuli intensity of different visual variables in isolation on people's ability to perceive different types of popout effects. Our first study extends this previous work to determine the effects of using combinations of popout cues on people's ability to perceive the effects. The presentation of targets was experimentally controlled to test three different types of popout (color, motion, and shape), their paired combinations, and all three combined. Each condition was tested at five different levels of intensity, and at six horizontal angle locations (duplicated for each side) covering different regions of the human visual field.

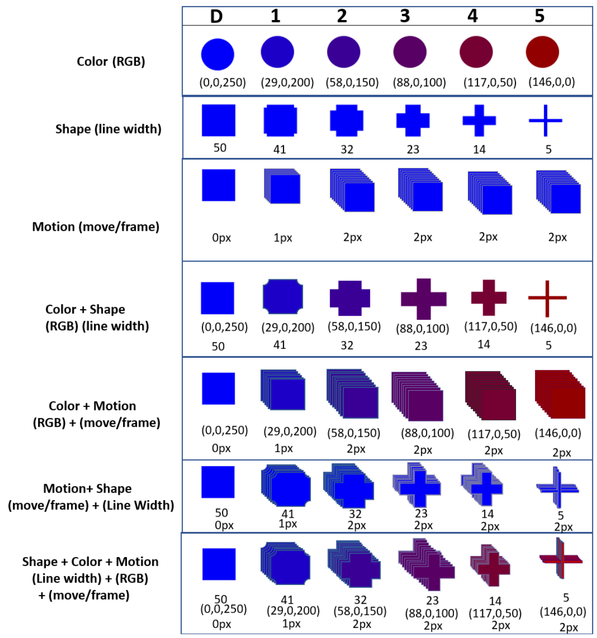

Figure 2: Distractor (D), Visual Variables and Intensity Levels (1-5, and value for level). Note: Motion is capped at 2 when combined.

Visual Variables

Following previous studies [19] we chose color, shape, and motion as our visual variables, as these provide varied performance across their different levels of intensity across the visual field. This would allow us to see whether combining these variables (e.g a strong variable and a weak variable) has any effect on performance. The variables, levels, and distractors used are shown in Figure 2. In all combinations with motion, we capped motion at level 2, to prevent potential ceiling effects observed in previous studies and our own pilot tests. For motion cues, movement direction was diagonal (down and to the right, with displacement applied equally to x and y axes), and was animated using 17 frames during the 240ms presentation. A black background was used for all object presentations. With five levels for each of the seven visual variables, there was a total of 35 conditions in the study.

Visual Angles

For consistency and comparison, we presented our visual variables at the same angles as those of Gutwin *et al.* [19]. Six horizontal target locations were chosen (duplicated for left and right); three angles covering the near peripheral region (±6°, ±18°, and ±26°), and three covering the mid-peripheral region (±38°, ±50°, and ±62°). Angles were measured from the center vertical line. We placed targets at ±8° from the center horizontal (upper and lower locations were collapsed for analysis).

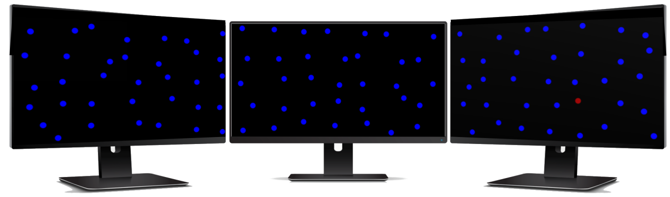

Figure 3: Visual field for a trial

Participants and Apparatus

Twenty-one participants were recruited from the local university community (8 male, 13 female) and were given an honorarium of $20. The average age of the participants was 25 (SD 4.4). Participants reported normal or corrected-to-normal vision and no color-vision deficiencies; all were experienced with mouse-and-windows applications (10 hrs/wk).

The study used a three-monitor setup with three Asus 27-inch UHD LCD panels (Figure 3) arranged in a curve so that the participant was 75cm from the center of all three screens, providing a visual workspace of 11,520x2160 pixels. Monitors used identical settings for contrast, brightness, gamma, and white balance. All three monitors were driven from a single Nvidia GTX 1080Ti graphics card and a Windows 10 PC. We built a custom experimental system in Processing for the study that presented all trials (in full-screen mode) and recorded performance data. All questionnaire data was collected through web-based forms.

Study Procedure

Participants completed informed consent forms and demographic questionnaires. All participants first completed a set of practice trials with a different visual variable to those used in the main study (flashing). They were then assigned to a random order of presentation of the visual variables (color, shape, motion, color+shape, color+motion, motion+shape, color+shape+motion). Participants carried out a series of trials for each intensity level of the first visual variable, in order from most intense to least intense (five levels). After completing all the intensity levels of a visual variable, participants completed a NASA-TLX subjective workload questionnaire [20] and proceeded to the next of the 7 visual variable conditions.

Color and shape were presented at five intensity levels. Motion was presented at five levels when the variable was used alone, but motion was capped at level two when combined. There were two blocks of trials for each condition. The visual variables were presented across 12 horizontal angles

(6 for each side), and 2 vertical locations for each angle, for a total of 48 trials per block. Before each intensity level began, the study system showed how each target would look for that level, and presented the distractors. The target maintained the same appearance for all 48 trials of the level. Across all levels and blocks, each visual variable was presented in 240 trials; a single condition took approximately 20 minutes to complete. Participants were allowed to take breaks after each block.

The visual field was hidden after each trial and the study software then asked the participant to state whether they saw the target object (with particular visual properties for the particular level) e.g., "Did you see a moving square among the blue squares?" Participants could press the '1' key for "yes" and the '0' key for "no" to answer. For consistency with previous studies, each trial presentation lasted 240ms. 240ms also prevented participants from refocusing their gaze to search for the stimulus. For each trial, participants were asked to focus on a fixation cross at the center of the middle monitor. After a random interval of 1-2 seconds (to avoid anticipatory action), a field of objects containing 104 distractors was presented for 240ms (Figure 3). The 104 distractors were distributed quasi-randomly across the three monitors (avoiding overlaps), along with one target object in some trials. For consistency with previous studies, the popout target was shown in 60% of trials [19].

Study Design and Analysis

The study used a repeated-measures within participants design, with accuracy (percentage of correct responses) in target-present only trials as our dependent measure, and three factors:

- *Visual Angle*: The horizontal angle our variables were presented (±6°, ±18°, ±26° ±38°, ±50°, and ±62°).
- *Variable*: The visual variables used to create a popout effect (color, shape, motion, color+shape, color+motion, shape+motion, color+shape+motion).
- *Intensity Level*: The discriminability between our target visual variable and the distractors (Figure 2).

Responses to the TLX-style questionnaire were also analyzed.

STUDY 1 RESULTS

Data Check: Target-non-present Trials

Participants could have guessed 'yes' or 'no' in every trial, regardless of the presence of the popout stimuli. We calculated the mean accuracy for trials where the target was not present as a way to test the credibility of each participant's responses. Accuracy in these trials for all visual variables was above 90%, suggesting participants answered honestly throughout the experimental conditions.

Accuracy: Main Effects of Angle, Variable, and Level

Our analysis used only the target-present trials, since these are the trials that matter most to the perception of the different visual variables. Overall, perception accuracy decreased substantially as the visual angle increased – from 83% at ±6° from the center to less than 20% at ±62° (Figure 4). RM-ANOVA showed a strong effect of *Angle* on accuracy ($F_{11,198} = 324.25, p < 0.0001$).

RM-ANOVA showed strong effects for *variable* ($F_{6,108} = 265.75, p < 0.0001$) and *level* ($F_{4,72} = 246.72, p < 0.0001$) on accuracy. Averaged across all levels, accuracy for each condition ranged from 76% for motion, 67% for the combination of color+motion, 58% for shape+motion and 60% for the three-way combination, down to 34% for color, 33% for color+shape and 18% for shape. Bonferroni-corrected post-hoc t-tests showed significant ($p < 0.001$) differences between each variable pair except for Color → Color+Shape, and Motion+Shape → three-way combination. A similar post-hoc t-test was applied for pairs of intensity levels and showed a significant ($p < 0.001$) difference between all pairs. However, the main effects of *Variable* and *Level* must be considered in light of the interactions described below.

Interactions Between Angle, Variable, and Level

RM-ANOVA showed significant interactions between Angle and Variable ($F_{66,1188} = 25.10, p < 0.0001$), Angle and Level ($F_{44,792} = 13.84, p < 0.0001$), and between Variable and Level ($F_{24,432} = 29.41, p < 0.0001$); there was also a three-way interaction ($F_{264,4752} = 13.33, p < 0.0001$). RM-ANOVA also showed an interaction between *Side* × *Angle* ($F_{5,95} = 2.84, p < 0.01$) and *Variable* × *Side* ($F_{6,114} = 2.97, p < 0.001$).

These data are shown in Figure 4. Accuracy with different visual variables responded differently to increasing angle and intensity level. Accuracy with motion (capped at level 2) remained high and constant across intensity levels, often reaching a performance ceiling, even at wide angles. Performance with Color or Shape followed a bell-shaped curve across *Angle* at levels 2 and higher; accuracy remained flat at level 1 across *Angle*. Accuracy with the pair-wise combinations of these variables often mirrored the performance of the strongest variable by itself, as shown by the performance of Color+Motion which essentially mirrors Motion alone, and Color+Shape which mirrors the accuracy of Color alone, particularly as demonstrated in the color+shape graph at level 4. The interpretation of these interactions is considered further in the Discussion section below.

Left-Right Analysis

RM-ANOVA showed a significant main effect of side ($F_{1,18} = 4.7, p < 0.001$). Averaged across all variables and levels, overall accuracy was 51% for the left side and 49% for the right

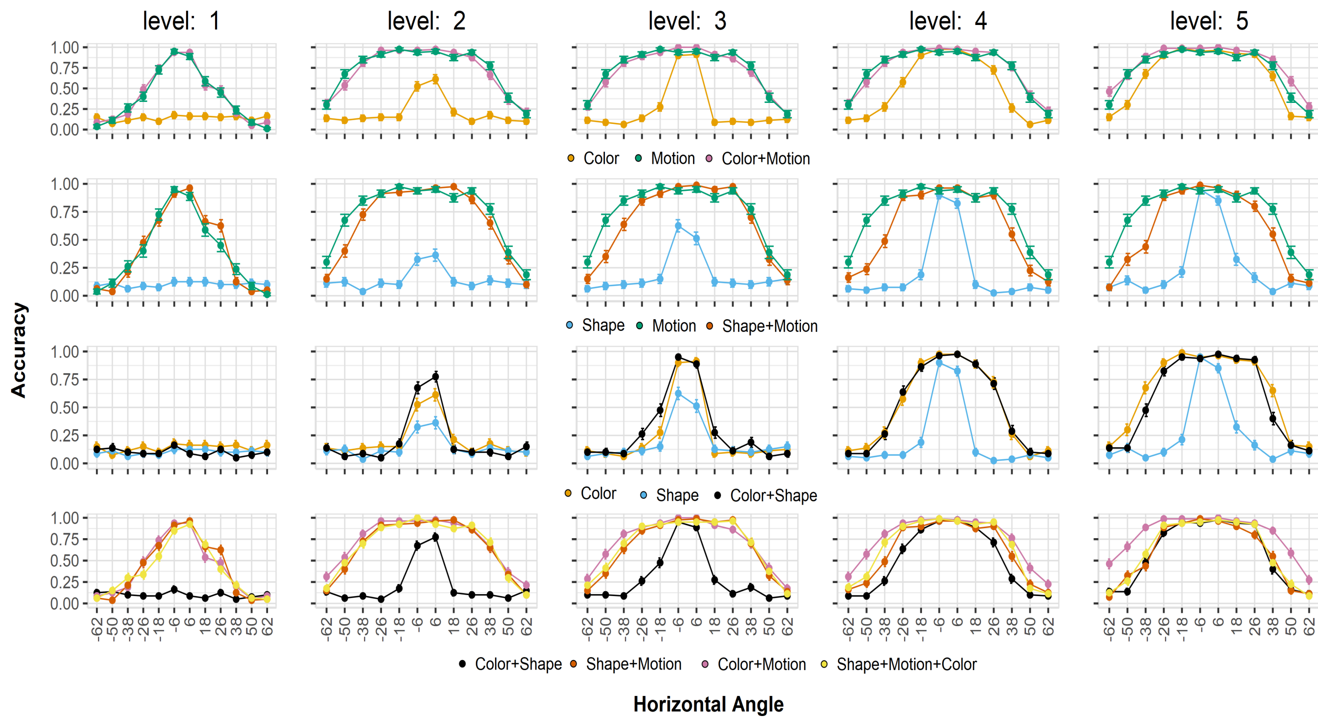

Figure 4: Accuracy (±s.e.) by Variable (rows), Intensity Level (columns), and Angle (x-axis). Target Present only Trials.

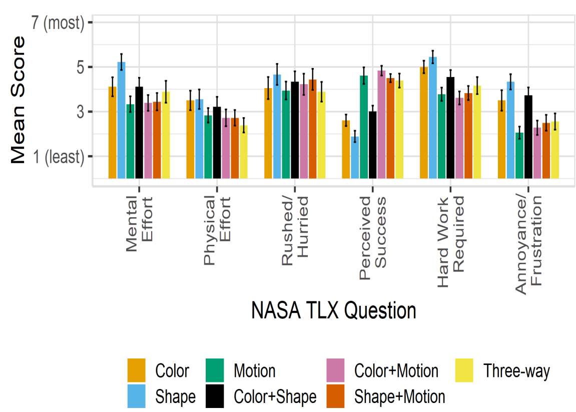

Figure 5: Mean NASA-TLX questions responses (±s.e.).

side. Follow-up Bonferroni-corrected one-way comparisons of opposing sides of paired angles showed significant differences between ±62°, and ±50°, both favoring the left side (left: accuracy of 17% and 30%; right: 16% and 24%).

Perception of Effort

After all tasks were completed for each visual variable, participants filled out an effort questionnaire based on the NASA-TLX survey. Mean response scores are shown in Figure 5. Effort scores approximately follow the performance results above: Across all levels and angles, combining two visual features yields no significant advantage in terms of perceived effort over the better of the individual features alone. However, Friedman tests showed significant differences ($p < 0.05$) between all subjective measures for the visual features except for rushed pace ($p = 0.27$) - these primarily indicate differences between the individual variables (color, motion, and shape).

STUDY 2: APPLIED POPOUT, DISTRACTION AND TASK INTERFERENCE

As most notifications are employed away from the center of the screen while a user focuses on a primary task, we need to understand how peripheral noticeability changes when a user is working on a primary task dominated by other visual effects, as well as any unintentional distraction the notifications might create. We designed our study following a similar method to Study 1, but with the following adjustments.

Peripheral Notification Design

As we intended our second study to be a closer representation of real-world settings, we could not use the fixation cross as in Study 1; instead, we dynamically placed the popout notifications at different angles based on the user's viewpoint which we approximated by the location of the snake's head in the game (described below). We removed the angles that cover the near peripheral region (±6°, ±18°, and ±26°) for two reasons: first, their accuracy was close to a performance ceiling regardless of intensity level and condition; and second, most real-world desktop notifications are displayed away from the center of the screen.

As noted from Study 1, we can predict the performance of combinations of stimuli through the strongest variable. We therefore removed the combinations (color+shape, motion+color, motion+shape) of visual variables (we ran a small pilot to confirm that these combinations did not perform better even with the task of Study 2). For the motion visual variable, we did not cap the level as in Study 1 - therefore, motion varied from level 1 to level 5. We also removed the shape variable to reduce the amount of time needed for the study, leaving two popout conditions; color and motion. We added a *score* variable to keep track of user performance in the main task during the presentation of the various popout stimuli.

Two Logitech C270-HD web cameras were mounted to each of the side displays (left and right). The system captured camera frames and processed them with a face-detection algorithm (Haar CascadeClassifier from OpenCV (opencv.org)). The OpenCV algorithm reliably detects a face if visible in the camera frame and looking towards the camera in a range from −45° to +45°. The camera was pointed towards the user (mounted on the monitor); this means that when the user looked away from the screen, the recognition algorithm failed to see a face in the image. The face detection served as an approximate method to check our dynamic presentation of the peripheral notifications.

Main Task: Snake Game

The main task of our second system was based on the arcade game *Snake* (Figure 6). Participants maneuvered a line (the snake) with the cursor keys across the three screens which grew in length after eating each target (a green block representing an apple), thereby increasing the score by one. The line itself served as the primary obstacle. The moving snake was a source of potential interference for the perception of motion in the notifications. We also added distractors (similar to the ones in Study 1) distributed randomly across the three screens, which also moved down the screen (contrary to the diagonal movement of our motion cue), at varying speeds from 1-3px per frame (our motion cue used the same 1-5px per frame range as study 1). The distractors also served as obstacles, with a one point score deduction if the snake hit an obstacle, ensuring participants would stay focused throughout the task, and allowing us to quantify mistakes made during the presentation of the different visual cues. Participants used the arrow keys to move the snake and had to press '1' when they saw a visual stimulus (the system

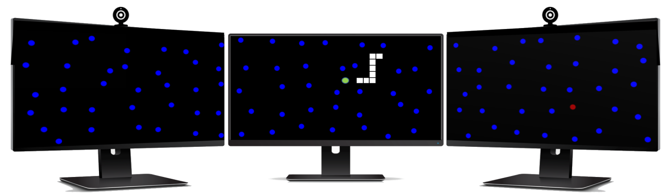

Figure 6: Experimental setup for Snake Game

did not pause as it did in Study 1). Each trial (i.e., the time window in which the stimulus would be flashed and the participant could answer) lasted 10 seconds. Stimuli were flashed at random intervals from 2-8 sec within the 10 second trial window (to prevent anticipatory reaction). Participants had to respond within one second of the stimulus flashing for their response to be recorded as correct. Failure to respond would mark the trial as a 'miss', but would carry no penalty to the game score.

Study Design and Analysis

The study used a repeated-measures analysis of variance (RM-ANOVA) within-subjects design, with accuracy as dependent measure and three factors:

- *Variable*: Color, Motion
- *Angle*: Horizontal angles (±62°, ±50°, and ±38°) calculated from the location the participant is looking at (based on snake head, and checked with webcam feed).
- *Level*: Intensity level (five levels per variable).

To measure the distraction of the different popout effects, the game score acted as a second dependent measure, with Variable, Angle, and Level as factors (all within-subjects).

Participants and Apparatus

20 new participants were recruited from the local university pool (11 male, 9 female) and were given an honorarium of $10 for their participation. The average age of the participants was 26 (S.D. 3.8). Participants reported normal or corrected-to-normal vision, no color-vision deficiencies, and were all experienced with desktop applications (more than 10 hrs/week).

STUDY 2 RESULTS

Data Check: WebCam Face Detection

The OpenCV algorithm indicated that the eyes were detected in the display containing the snake in 69 % of the trials. However, there was high false-negative rate due to the angled displays (i.e., a participant may be looking at the snake located at the edge of one of the side displays, and the openCV algorithm may fail to detect their face). As such, we can assume a higher rate of participants looking at the correct display during a trial.

Accuracy: Main Effects of Angle, Variable, and Level

As expected following the results of our first study, accuracy decreased substantially as the visual angle increased – from 73% at ±26° to less than 48% at ±62°, summarized in Figure 7. RM-ANOVA showed a strong effect of *Angle* on accuracy ($F_{7,133} = 14.01, p < 0.001$). RM-ANOVA, however, did not show a significant effect of *variable* ($F_{1,19} = 0.009, p = 0.9$) or *level* ($F_{4,76} = 1.93, p = 0.11$) on accuracy. Averaged across all levels, accuracy was 64% for motion, and 63% for color. RM-Anova found no interactions between *Angle* × *Level* ($F_{28,532} = 0.74, p = 0.82$), *Variable* × *Angle* ($F_{7,133} = 0.29, p = 0.95$) , or *Variable* × *Level* ($F_{4,76} = 1.26, p > 0.29$). There was also no three-way interaction ($F_{28,532} = 0.92, p = 0.57$).

Score: Main Effects of Angle, Variable, and Level

Our score variable was used to keep track of user performance during presentation of the different popout conditions, and serves as a rough measure of distraction (the cognitive load from attending to the popout conditions acting as visual notifications). On average, score during the presentation of the motion cue was lower across all intensity levels (Figure 8). RM-ANOVA showed significant main effects of *Variable* ($F_{1,19} = 6.29, p < 0.05$), and *Angle* ($F_{7,133} = 2.98, p < 0.01$). RM-ANOVA also showed a significant interaction between *Variables* × *Angle* ($F_{7,133} = 3.01, p < 0.01$). There was no significant difference between *Levels* ($F_{4,76} = 0.70, p = 0.59$) or an interaction between *Variable* × *Level* ($F_{28,532} = 0.44, p = 0.20$) or *Level* × *Angle* ($F_{28,532} = 0.44, p = 0.99$). There was also no three-way interaction ($F_{28,532} = 0.91, p = 0.59$).

Left-Right Analysis

RM-ANOVA found a significant difference between sides ($F_{1,19} = 10.44, p < 0.01$) with an average accuracy across both variables of 67% for the left, and 61% for the right. There was no interaction between *Variable* × *Side* ($F_{1,19} = 0.02, p = 0.66$).

Perception of Effort and Distraction

We asked participants to complete a NASA-TLX score questionnaire after completing experimental trials for each condition. The mean scores are shown in Table 1. Friedman tests on each measure showed no significant differences between the conditions, except for mental effort.

After trials for a condition were finished, we asked participants to rate (on a 1-7 scale) which visual variable they perceived as being easier to notice, which was more distracting to the game, whether the visual variable had caused them to die in-game (Table 2), and their reasoning behind the answers.

	Color	Motion	X^2	P
Mental effort	3.5 (1.9)	2.6 (1.5)	6.2	.01
Physical effort	2.9 (1.6)	2.5 (1.1)	3	.08
Rushed pace	2.8 (1.3)	2.8 (1.2)	0	1
Perceived success	4.1 (1.3)	4.1 (1.3)	0.3	.6
Hard work needed	4.0 (1.8)	3.8 (1.4)	0.7	.4
Frustration	3.0 (1.9)	3.2 (1.9)	.09	.7

Table 1: Mean (s.d.) NASA-TLX scores (1-7 scale, low to high), Friedman χ^2 value, and p-value

	Color	Motion
Distraction (avg. after condition)	3.5	3.1
Variable caused in-game death? (count)	11	12
Easier to notice (count)	10	10
Most Distracting (count)	11	9

Table 2: Participant Preference.

Despite the difference in *score* across the two visual conditions, participant comments suggested that people perceived the two variables as fairly similar in distraction and noticeability during gameplay. One person said that they felt less distracted by motion: "The blue moving circle felt more like a part of the game". Another participant commented "The moving circle made its appearance more discernible to me, it caught my eye without taking me away from the snake". Participants who favored color, however, noted that color had "Higher contrast with the background", which made it easier to notice; another participant stated "high contrast helped me to pick it (color) out."

4 DISCUSSION

Summary of Findings

Our two studies provide several findings:

- Combining visual features does not improve instantaneous noticeability in the periphery; performance is often dominated by the better of the variables.
- There are variations in how the noticeability of different popout variables changes depending on the visual characteristics of the primary task - motion in the task may have interfered with motion in the notification.
- Popout features have significantly different effects on primary task performance.
- Participants consider popout variables that "blend in" with the primary task as less distracting.
- Participants showed a bias towards the left side of the visual space.

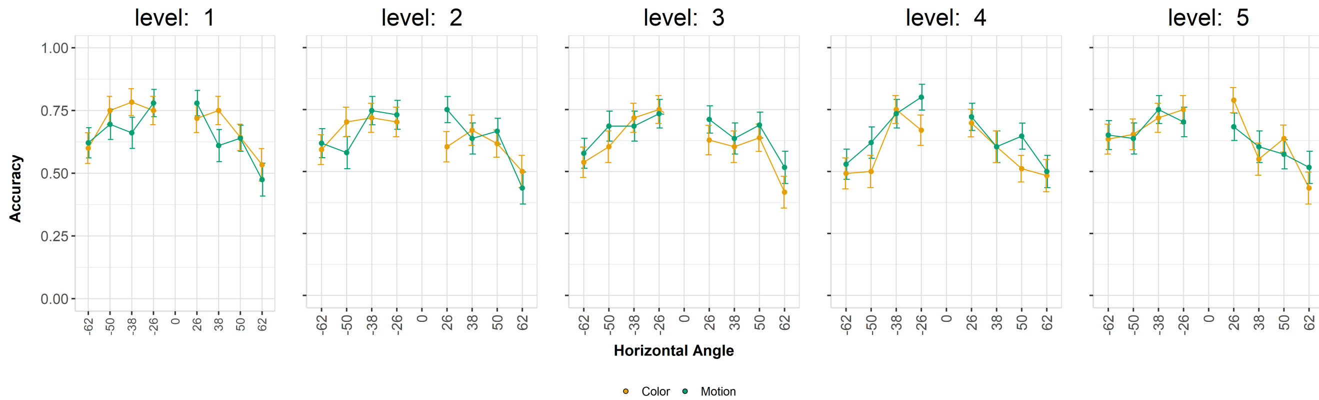

Figure 7: Accuracy (±s.e.) by Variable (rows), Intensity Level (columns), and Angle (x-axis) in Snake.

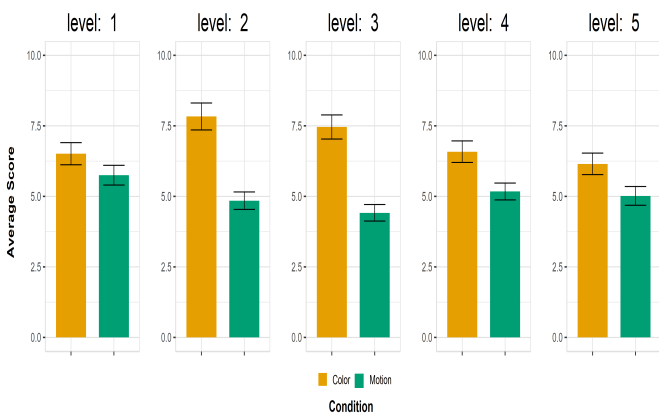

Figure 8: Game score during presentation of visual variable.

Explanation of Results

Our finding that feature combinations do not offer an improvement in noticeability is probably best explained through prior findings that saliency detection mechanisms are not completely independent (e.g., [33]), as reviewed in an earlier section. However, to the best of our knowledge, the additive (or non-additive) effects of visual combinations have not been studied in the periphery, and there is little reason to suspect that findings for experiments involving stimuli in or near the foveal region will generalize to peripheral stimuli due to the different visual mechanisms used in these regions [25, 49].

The intensity levels for color and motion tested in our experiments are intended to be generalizable for notification design in user interfaces. While we did not find clear additive effects for color and motion combinations, we note that color reached the lowest accuracy (37%) plateau in the periphery, albeit with a high (79%) overall precision rate. To better investigate additivity of features, future studies should ensure that visual features are clearly visible and easily detected, however performance should not be at the ceiling level.

As shown in Fig 4, there is a sharp decline in accuracy in the peripheral angles. Perceiving objects and shapes in the periphery is difficult, particularly when surrounded by similar objects. Impaired ability to recognize objects in a cluttered environment is often best explained by the phenomenon of visual crowding [26]. Crowding represents a visual bottleneck, and occurs with a wide range of objects, colors and shapes [26]. Visual crowding increases proportionally to the eccentricity (angular distance from foveal vision) of the visual target [2, 9]. While our experimental setup controlled the presentation of visual stimuli so that distractors and stimuli would not overlap, changes in the distance between distractors and visual notifications may affect peripheral noticeability, particularly as angle increases.

The Snake Game in our second study had strong motion effects (i.e., the snake's movement and the distractors), and accuracy with *Motion* dropped in comparison to Study 1's findings (unlike *Color* which was more accurate in Study 2 than Study 1). Lower accuracy with Motion was independent of the visual angle, and thus not restricted to a user's periphery. Researchers have investigated how motion is processed, with results suggesting that search for a fast moving target among slow or stationary distractors is more efficient than searching for a slow target among fast distractors [16, 22]. However, a clear explanation to the process driving motion results is still lacking [37]. In general, it seems likely that the motion of the snake (and possibly the distractors) reduced the salience of the motion popout stimuli.

Results from both studies showed higher detection accuracy in the left side of the visual field. This finding conforms with prior research in perceptual psychology, with most results showing an advantage to the left visual field [10, 13, 44], including attentional resolution [21], motion processing, and contrast sensitivity [12].

Design Implications

Our findings are applicable in a number of different contexts. Interface designers often need to draw a user's attention to notifications, but they risk distracting users when doing so. These studies improve understanding of how peripheral popout cues are detected while offering insights on the undesired distraction that they may cause. While the current set of popout stimuli examined was relatively small, we intend to explore further visual variables and other combinations.

A first design implication is that combining features to achieve greater noticeability may not achieve the desired effects. Simple features can achieve noticeability and the benefits of combining features in an attempt to increase saliency are questionable. Bertin suggests that variations in individual visual variables are effective for encoding information and achieving noticeability [7]. Particularly, *selective visual variables*, such as position, size, color hue, or texture allow observers to immediately detect and isolate variables based on changes.

A second design implication is that motion effects, while noticeable across the visual field, may have a negative effect on primary task performance. This may be because motion is more distracting, requiring a greater cognitive load to attend to than other popout effects. Previous research on interruption suggests that a scheduled interruption (such as our popout stimuli during gameplay) is one of the most detrimental for primary task performance [31]. Some situations require notifications that do not disrupt a primary task, and in these contexts motion may be a poor choice for notifications unless the notification's purpose is urgent. More work is needed to further explore these issues.

Limitations and Future Work

There are many opportunities for extending our findings. First, both of our studies investigated the effects of a single popout target at a time. It is possible that noticeability for popout stimuli changes when there are multiple concurrent targets, creating opportunities for further work.

Second, we explored additive effects with color, shape, and motion, but there are many other possible combinations that should also be tested. In particular, manipulating the size of a stimulus should be considered, because increased screen space in large-display environments provides the opportunity to increase notification size without cluttering the visual space. Previous work suggests that size is easily perceived by viewers [7], although there are few results that consider peripheral vision. A related opportunity is to explore the noticeability of realistic icons across the visual field. Icon noticeability could be amplified by combining icons with popout effects such as motion or changing luminosity. The popout stimuli we studied also had no intended meaning (i.e., a red circle was not intended to mean "danger"). Another opportunity is to explore the effects of training and familiarity on popout identification.

A third area of future work is examining the relationship between visual presentation time and noticeability, and different primary task visual variables. An increased presentation time of a peripheral notification may have notable effects on distraction. It is possible that a different variable (other than motion) in the primary task will have different effects on the noticeability of the studied visual cues. Further research is also needed to investigate the distraction effects of different stimuli and scheduled interruptions.

5 CONCLUSION

Notification systems are integral to interactive desktop environments. Designers, however, are often required to address a trade-off between desired noticeability and unintended distraction – a trade-off that becomes more complex in large-display settings. Results from two studies suggest that strong standalone popout cues are as effective in achieving peripheral noticeability as popout feature combinations, which is a common design strategy for achieving greater noticeability. Our second study showed that these noticeability results also hold when notifications are used in a more realistic task setting that demands the user's visual attention – although there was potential interference between the motion used in the primary task and the effectiveness of motion in the peripheral notifications. Furthermore, we investigated the issue of peripheral notification distraction to primary tasks, demonstrating that motion appeared to have an adverse effects on primary task performance. This work increases understanding of how people perceive popout features when used as peripheral notifications, which is particularly relevant for designers of interfaces and visualizations used in large displays and multiple-display environments.

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