Peripheral Notifications: Effects of Feature Combination and Task Interference

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ABSTRACT

Visual notifications are integral to interactive computing systems. 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. 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. With large displays, 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 is working on an attention-demanding task. We addressed these questions by conducting two studies. We conducted a laboratory study that tested people's ability to detect popout targets that used combinations of three visual variables. After determining that the noticeability of feature combinations were approximately equal to the better of the individual features, we designed an experiment to investigate peripheral noticeability and distraction when a user is focusing on a primary task. Our results suggest that there can be interference between the demands of primary tasks and the visual features in the notifications. Furthermore, primary task performance is adversely affected by motion effects in the peripheral notifications. 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.

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This thesis is dedicated to my dad - who only got to see the a part of this, but I know he would have been proud.

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LOF   List of Figures
LOT   List of Tables
MDE   Multiple Display Environment

Chapter 1

Introduction [1]

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 [64]. These visual notifications are employed in a variety of desktop applications including instant messaging systems, news, weather, sports, and status programs. A variety of visual effects can potentially be used to design and create engaging notifications; however, a balance must be struck between various design goals.

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 [62], mistakes [7], and productivity loss [27]. The design of visual notifications, therefore, is a task that requires careful attention - designers must ensure a balance where urgent notifications are able to quickly command a user's attention, while the least important notifications do not distract users from their main task.

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 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 further from central vision [42]. Therefore, on large displays, notifications that

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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 peripheral vision.

New design considerations imposed by larger screens in computing environments are not limited to the design of peripheral notifications. Highlighting and emphasis in information visualization, for example, utilizes similar fundamental concepts from visual perception to guide a viewer's attention as those used in notification design [43]. With increased display size, most of an interactive visualization will be in the user's periphery; users will potentially miss out on important information located outside their central vision unless correctly guided to these salient locations. While previous work provides a foundation on how humans perceive stimuli in their peripheral vision, there are still several important questions that need to be investigated.

1.1   Problem and Motivation

The problem addressed by this thesis is: *there is little known about how visual features of notifications, and their combinations, affect noticeability and distraction across the visual field.*

Adding visual features to increase salience is a common design strategy, but research in perceptual psychology suggests that the different perceptual pathways for different features may not be independent [74, 5], and little is known about how combinations of features actually affect noticeability. Understanding how visual features work in a user's periphery is important for the design of peripheral notifications when most of the display content is in the user's visual periphery, and when notifications typically appear on the edges of the display.

In most situations, users divide their attention among various tasks, stimuli, and events. Most modern theories of attention suggest that people have a limited capacity [111, 6], and we cannot attend to everything around us. Most research so far has focused on measuring noticeability in isolation, without studying the effects of distraction and the interaction between noticeability and distraction. As most notifications are employed while a user focuses on a primary task, we need to understand how (and whether) peripheral noticeability of notification-style visual features changes when a user is working on a primary task comprised of many visual features, and its effects on primary task performance.

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1.2   Solution

To answer these questions about how visual features and their combinations affect noticeability and distraction when used as peripheral notifications we carried out two user 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 a previous study [42], we selected color, shape, and motion as our visual variables, as they provide varied levels of noticeability on their own. Participants were shown visual targets for 240ms, at different intensity levels, in a triple-monitor setup that allowed us to present the targets up to 62° from the center in both directions. This first study provides a better understanding of how visual features operate when used as peripheral notifications.

Our second study focused on investigating peripheral noticeability and distraction when a user is working on a task. We asked participants to detect a subset of the popout targets used in Study 1 while they played a modified version of the arcade game Snake [1]. This second study provides a better understanding on how the noticeability of different visual features changes when a user focuses on a task. The study also provides an understanding of the cognitive load required to attend to different visual features by measuring the distraction caused to the primary task.

1.3   Steps to the Solution

There were multiple steps involved in accomplishing our end goal of understanding the noticeability and distraction effects of notification-style visual features across the visual field.

- **Create a Framework for Peripheral Notification Design:** In order to assess visual features for notification design, the first step is to consider what is necessary for the design of the notifications. Several design qualities were identified as desirable characteristics for peripheral notifications: peripheral notifications must be noticeable from wide angles when users are working in large displays; however, these notifications must not be overly distracting to users.

- **Identify a Set of Visual Features Common in UI Design:** The initial steps involved identifying a set of visual features that are common in user interface design, specifically, visual features that are (or can be) commonly used for notification design. An additional requirement to selecting a set of visual features was that these visual features could be easily combined, so

that we could measure their noticeability, both in isolation andin combination. Finally, our set of visual features had to be selected in a way so we could provide different levels of "intensity", allowing us to measure, quantify, and understand each visual effect and its varying degrees of noticeability. Once we had established the set of visual features we would be examining, we had to determine their noticeability and distraction effects.

- **Implement a System to Evaluate Visual Features:** To accomplish our goal of measuring noticeability of visual features, we created a custom system that allowed us to present the selected visual variables among distractors in a triple monitor setup, which allowed us to measure noticeability of individual visual features and their combinations up to $\pm62°$ of the human visual field. The system and visual variables used are described in detail in Chapter 3.

- **Evaluate the noticeability of Visual Variables:** To investigate the noticeability of visual variables, we set up a signal detection study where we showed participants a set of objects on the screen for 240ms, which contained a visual target in 60% of the trials; we then asked participants whether they saw the target. The presentation of targets was experimentally controlled to test three different visual variables (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. This study provided data to evaluate the visual variables and their combinations based on user's accuracy in detecting the visual target in trials when it was present.

- **Implement a System with a Primary Task:** Our next step then focused on measuring if (and how) noticeability of visual variables changes when a user focuses on an attention-demanding task. Having the user focus in a primary task also allows us to measure their performance in the task, as a way to understand the distraction caused the presentation of visual variables.

We designed a second system where the user focused on a visual task (similar to what a user may focus on a daily basis) that would allow us to measure changes in the noticeability of the visual notifications, as well as their effects on the primary task performance. We used a similar setup to study 1, with a subset of the visual variables, but we included a modified version of the game Snake [1], as its main control tasks (moving with arrow keys, selecting

items, avoiding distractors) would keep a user engaged.

- **Testing the Visual Variables when Users Focus in a Task:** We set up a study where users would be presented with the visual variables while they played the snake game. Users were asked to respond by pressing a key whenever they noticed a specific visual stimulus appear on the screen. This study provided data to understand how peripheral noticeability changes when a user is working on a primary task dominated by other visual effects, based on the user's accuracy in detecting a visual variable while playing the game. Furthermore, this study presented insights on the unintentional distraction that notifications might create, based on the user's performance on their task during the presentation of the different visual variables.

1.4   Evaluation

We conducted the two user studies, we first evaluated peripheral noticeability of feature combinations. Second, peripheral noticeability and distraction were evaluated when users focus on an primary task comprised of numerous visual features. Subjective responses were also gathered to measure subjective noticeability and distraction. Our participants completed NASA TLX [45] style questionnaires and responded to open-ended questions about their preferences and distraction. Our two studies provide several new findings about people's ability to perceive stimuli in the visual periphery. The key findings were as follows:

- Combinations of visual variables (e.g., any combination of colour, shape, and motion) were always approximately equal to the better of the individual features. This finding suggests that simple features can achieve noticeability, and that there is little benefit in combining features in an attempt to increase saliency.

- There was interference between the visual features of the primary task and notification (in particular, the salience of motion in peripheral notifications was diminished when motion was part of the primary task). Color, however, was not negatively affected by the primary task.

- Primary task performance indicates participants were distracted by the visual effect of motion. Motion effects, while noticeable across the visual field, may have a negative effect on primary task performance.

- In a short follow up study, we doubled the presentation time of our visual variables (from 240ms to 480ms). While these results are highly exploratory, preliminary findings suggest a non-linear relationship between presentation time and noticeability.

1.5 Contribution

This thesis provides two major contributions that provide a better understanding of how visual features operate when used as peripheral notifications. First, combining visual variables (e.g., any combination of colour, shape, and motion) does not improve noticeability in the visual periphery. Through our empirical evaluation of the different visual stimuli, we were able to determine that the noticeability of paired combinations of visual stimuli was similar to to that of the strongest (most salient) visual stimuli on its own.

Our second main contribution is in identifying that there can be interference between the features of the primary task and the visual features in the notification, both for noticeability and distraction. From our empirical evaluations, we learned that the noticeability of motion stimuli decreased when users where focusing on a primary task that involved motion. Third, our analysis of primary task performance showed that participants were significantly more distracted by the visual effect of motion than the visual effect of color.

There are also two minor contributions:

- We provide design guidelines for using our results to improve the design of notifications, to better achieve noticeability when designing for large information spaces.

- The systems developed for evaluating peripheral noticeability and distraction, outlined in Chapter 3, were made easy to modify and expand - allowing for a variety of visual stimuli to be added and tested in a variety of settings, primary tasks, and display sizes in future research.

1.6 Thesis Outline

This thesis is organized into several chapters. To understand how users respond to particular visual stimuli, it is necessary to understand the underlying neural phenomena that dictate how we perceive visual and process visual stimuli. Chapter two provides a synthesis of related research on stimuli noticeability and vision processing which provide the foundation for the research presented in this

thesis. We present how human vision is processed. We then synthesize numerous theories on visual attention. Third, we discuss the implications of visual features on attention and distraction. Finally, we discuss previous research on notification design and current technical solutions.

Chapter three describes a design framework for peripheral notifications and the design of the systems that were used to evaluate peripheral noticeability and distraction across our studies. The system for evaluating peripheral noticeability was developed to show visual features that would "pop out" among numerous distractors. The system required a triple monitor setup that allowed us to show stimuli up to $\pm 62°$ away from the center of the human visual field. We provide a detailed explanation of the visual variables, intensity levels, and visual angles used in our studies. A second system was developed to measure the distraction caused by these visual features while users focused on an interactive task.

Chapter four presents the first study of the two studies. The purpose of this study was to determine the peripheral noticeability of feature combinations. A description of the procedure is given, followed by an explanation of our participant recruitment methods and their demographic makeup. The results of this first study are presented and analyzed. We also presents the results of a follow up to the first study, where we increased presentation time of visual features to investigate changes in peripheral noticeability given an increased presentation time.

Chapter five details our second main study, where we followed a similar study design and procedure to study 1, however, we focused on measuring peripheral noticeability and distraction as user focused on a attention-demanding primary task. Like in the previous chapter, a description of the procedure is presented, followed by our recruitment methods and our participant demographic makeup. The results from this study are presented and analyzed.

Chapter six provides details on a small preliminary follow-up study investigating the effects on noticeablity of our studied visual effects when presentation time is increased. We followed a similar study design and procedure to study 1, however, we doubled the presentation time of our visual variables. As in the two previous chapters, a description of the procedure is presented, followed by our recruitment methods and our participant demographic makeup. The results from this preliminary study are presented and analyzed.

Chapter seven provides a discussion of the results of the previous two chapters, as well as the implications of our findings. We discuss many of our thoughts regarding the limitations from our studies and systems, and the lessons we learned over the course of this thesis are presented.

Chapter eight concludes this thesis and summarizes our findings and contributions.

Chapter 2

Related Work

To understand how users respond to a particular visual stimulus, it is necessary to understand the underlying neural phenomena that dictate how we perceive visual and process visual stimuli. The following two sections summarize how the human visual system works as a pipeline, beginning with the detection and processing incoming visual stimuli from the eye - including reasons why some stimuli may be more easily detected than others. We then explain the events that happen to explain how we respond to the visual stimuli, particularly, the ways we attend to visual stimuli (i.e., shifting our focus to a more salient visual stimulus). The third section is concerned with using the knowledge from perceptual psychology to understand the design of visual stimuli for peripheral notifications and current technical solutions.

2.1   Neurology of Vision

2.1.1   The Retina and Photoreceptors

The processing of highly detailed visual scenes requires the capture of light information coming from the world, and does so through a complex information processing-chain. Human visual processing begins in the retina, the sensory organ of the human visual system, when rod and cone photoreceptor cells react to light energy [101]. The highest concentration of photoreceptor cells are located in a 1.5mm dent in the center of the fovea [83]. Photoreceptor cells in the retina convert light into neural signals through the activation of rhodopsin, a protein sensitive to light [88, 101]. When rhodopsin is hit by light, the chemical process called photoisomerization is triggered, and within 10 milliseconds, it causes a change in the electrical potential of the receptor membrane, generating a neural response [88].

The two main photoreceptor cells in the eye are cones and rod cells. Color-sensitive cone cells are predominantly located in the densely packed central foveal region of the eye [110], whereas rod cells are distributed more broadly across the retina and provide sensitivity to low light levels and
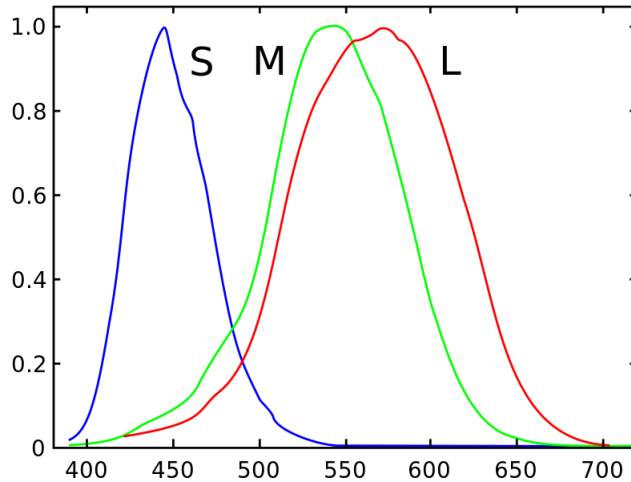
Figure 2.1: Normalized responsivity spectra of human cone cells, S, M, and L types. From Ezekowitz [33], data from Stockman and Sharpe [97].

assist in detection of shape and movement. Rods cells contain only one pigment, making them poor for color vision, but are extremely sensitive to light and can be triggered by a single photon [13].

Each cone in the retina is sensitive to a range of light wavelengths, but they each contain only one kind of rhodospin, making them particularly sensitive to specific set of light wavelengths (Figure 2.1). As explained by the Trichromatic Theory of Color Vision, normal colour vision is based on the activity of three types of receptors, at their different peak sensitivities. S-cones, sensitive to blue light, have their peak efficiency at 420 nm; green light-sensitive M-cones at 534 nm, and L-cones (red) at 664 nm. [88]. The different cones are distributed irregularly and available in different proportions in the human visual system [60]. There are 1.6x more L-cones than M-cones, and a very limited amount of S-cones. The higher number of L-cones results in a higher neuronal stimulation when presented with a red light in comparison to other colors [88].

The trichromatic theory explains how color vision at the photoreceptor level - with each photoreceptor reacting to different light wavelengths. It must be noted, however, that no photoreceptor is able to see color. The different signal responses are processed in later stages and are best explained by the Opponent-Process Theory of Color Vision. The opponent-process theory states that the cone photoreceptors are linked together forming three opposing color pairs: blue-yellow pair, red-green pair, and black-white pair [48] (Fig **??**). Cells can only detect the presence of one member of the pair at a time because the two members inhibit each other - explaining why there are some color combinations that humans are not able to perceive, such as a "blue-ish yellow" [48].
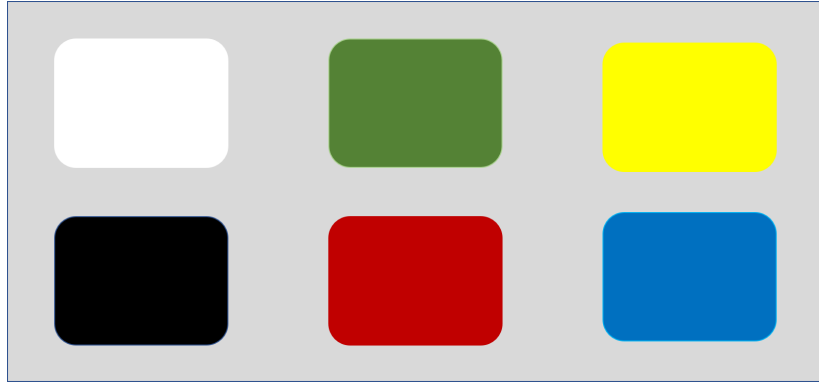
9

Figure 2.2: Opponent colors. Adapted from [109].

The Opponent Theory of Color was thought to be at odds with the Trichromatic theory for some time - but it is now generally understood that they both work together in the human processing center to process color. The cones are stimulated by light wavelengths and provide initial values used to create the three new opposing color pairs of channels. Each opposition pair is then encoded as a single channel, where detection of one of the colours stimulates the channel, and the opposing color inhibits it.

It should be noted, however, that some users suffer from various genetic conditions which cause atypical forms of color perception. These atypical forms of color perception are commonly called as color blindness or color vision deficiencies and happen when one or more types of cones are malformed due to genetic defects, resulting in difficulty distinguishing between colours usually detected by two different types of cones.

2.1.2 Neural Pathways and Visual Cortex

The main task of the eye is to transmit information about the world to the brain, and it does so using the photoreceptor cells, which are connected to the ganglion cells via neuronal circuits through the fibers of the optic nerve along at least three distinct pathways (Figure 2.3). 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 [52]. M cells have a high contrast sensitivity, and are essential for performing visual search and detecting changes in luminance [22]. P cells are smaller than M cells and are sensitive to color and are also involved in the analysis of shape and size. K cells respond to color and provide various other functions relating to spatial and
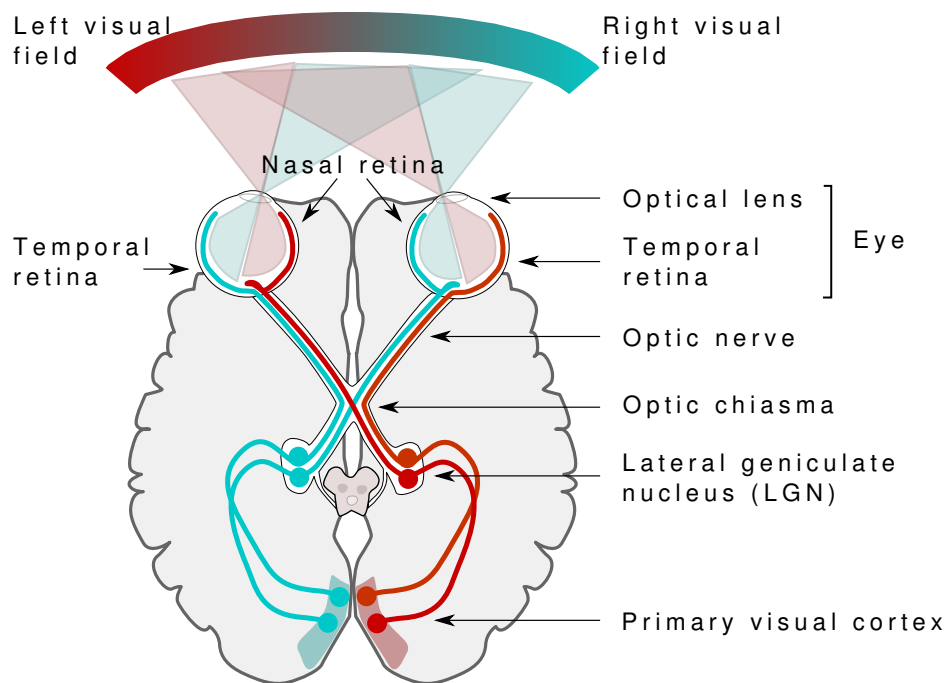
Figure 2.3: A simplified schema of the human visual pathway. From Nieto [73].

temporal vision [116].

Following the optic nerve through six different regions of the brain [88], the visual pathway includes the optic chiasm and the Lateral Geniculate Nucleus (LGN). Though not all functions of the LGN are fully understood yet, the LGN is considered as the pre-processing stage for vision processing, as it receives the input from both eyes and it stores image representations, compares the different image representations, thus sharpening spatial responses [88]. The LGN then projects the information to the main processing center for visual perception, the primary visual cortex (V1) [78, 88].

Cells in the primary visual cortex contribute to detection of visual stimuli, such as orientation and motion [74, 75, 18]. 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 [74]. Other feature combinations have been found to be more independent. For example, color-sensitive cells do not seem to encode the direction of motion; and motion sensitive cells have at most a minor role in detecting color [61]. For visual features that are independent and encoded by different cells, we might expect their saliency effects

to be additive; however, this need not be true if different visual stimuli are processed in temporal sequence (rather than in parallel).

2.2 Visual Attention

Eye movements can be divided into three types: Fixations, Saccades, and Smooth Pursuits. A *fixation* when the eye is directed and gaze maintained towards a particular target for a short period of time, placing the foveal region over the target for greater clarity [106]. *Saccades* are fast and short movements of the eye, directing gaze between visual targets. A *smooth pursuit* is when the eye moves continuously to closely follow a moving target.

Selective visual attention allows us to quickly guide our gaze towards objects in our visual field [104, 15, 20, 50], and it stems from evolutionary traits; helping organisms quickly detect preys or avoid predators. Researchers have observed that a salient stimulus will popout regardless of the scene contents and the number of distractors [102, 41]. The following section describes prominent feature detection theories, and explores how the limitations of our peripheral vision affect stimuli perception.

2.2.1 Feature Integration and Guided Search Theories

There are various theories and computational models of selective attention, but in general they agree that attention operates by alternatively selecting "features" of the incoming sensory data for further processing [87]. Early work suggests a two-stage process: first, a fast, pre-attentive stage, in which more-salient items draw attention [115]; second, a slower stage that is driven by current tasks and goals [85, 104, 56]. Within this model, the conjunction of basic features (such as color and orientation) stems from "binding" features together (known as Feature Integration Theory [104]). The Feature Integration Theory (FIT) is based on identifying a set of preattentive basic features, of which, a few, low-level basic features have been agreed by researchers and have been supported by a large body of data [115], including orientation [36, 114], color [103, 102, 72], motion [86, 31], and size [102, 90, 69] .

Other visual features have been found and proposed as guiding features, but are still in need of further research. It also clear that some aspects of shape can guide attention [102, 15], but the specific attributes are still debated. Other attributes such as shading direction [77], as well as vernier [21] and luminance [35] offsets have shown promising results. Arguments against these

possible features being guiding attributes stems from the fact that they can be reduced down to forms of color (in the case of luminance offset) and orientation (in the case of verner offset) cues [115].

Early theories were supported by classical visual search tasks where target features were found to guide attention [104, 113, 117]. There has been, however, an increasing amount of evidence for interest-driven attentional guidance. 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 [112]: 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 [89, 115, 87]. A new proposed model consists of three processes: current goals, selection history and physical salience (bottom up attention) [4]. They argue 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.

Theoretical and empirical research has been primarily based on visual search tasks, involving finding a particular feature of interest. The emphasis on visual search has been driven by the lack of models that predict search difficulty based on the confusability of the features of individual items. One of the reasons why predicting search performance is difficult is that search performance is constrained by the abilities and limitations of peripheral vision [84].

2.2.2 Limitations of Peripheral Vision

In order to understand the capacity of human vision, we must understand the limitations of peripheral vision [84]. Only a finite number of nerve fibers can emerge from the eye, with the highest concentration of cone cells located in the fovea, covering 5° of visual angle, providing a high-resolution foveal vision. Cone-cell density drops as we move away from central vision, were we become essentially color blind in our peripheral vision [12]. Other studies have shown that sensitivity to several visual stimuli are lower, with participants only able to detect one-tenth of the detail, in the periphery when compared to the fovea [94]. The human visual field covers approximately 210° horizontally (Figure 2.4) and is often divided into different regions based on visual performance [84].

- *Central* vision (also called foveal vision) is a person's visual focus, and allows people to read,

drive, detect colors, shapes and details sharply. Central vision has a high concentration of cone cells, and covers 5° of the visual angle (2.5° on each side from the center).

- *Paracentral* vision (also called parafoveal vision) is the region immediately surrounding foveal vision, covering 8° of the visual field (4° on each side from the center). Information in the paracentral vision can interact with information present in the fovea [54]. Paracentral vision has a lower density of cone-cells than central vision, but still has higher acuity than peripheral vision.

- *Macula*, containing two layers of ganglia, covers 18° of the human visual field, and is often defined as the boundary between central and peripheral vision [53, 57].

- *Near-peripheral* vision is the region on the human visual field between 8° and 30°. Visual acuity declines by approximately 50% every 2° from the center up to 30° [17], after which, acuity declines more steeply. A high concentration of rod cells can be found in the near-peripheral vision. Rod cell density declines towards the central region.

- *Mid-peripheral* vision is the region of the human visual field from 30° to 60°. Due to the increasingly lower density of cone cells, color perception becomes weak at 40° [2].

- *Far-peripheral* vision is the region of the human visual field starting from 60° up to the boundary at approximately 110°. The far peripheral vision remains largely under-researched, and some of its capabilities and limitations are still unknown [93].

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, most aspects of peripheral vision are substantially worse than 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 [94]). Previous research also suggests that peripheral vision constrains visual search performance [84]. A notable exception, however, is that our ability to detect motion remains relatively constant across the visual field [42, 106].

2.2.3 Signal Detection

Our sensory system is constantly exposed to multiple inputs, including a variety of visual stimuli; we filter out these inputs so we can selectively attend to what is most important. Signal Detection
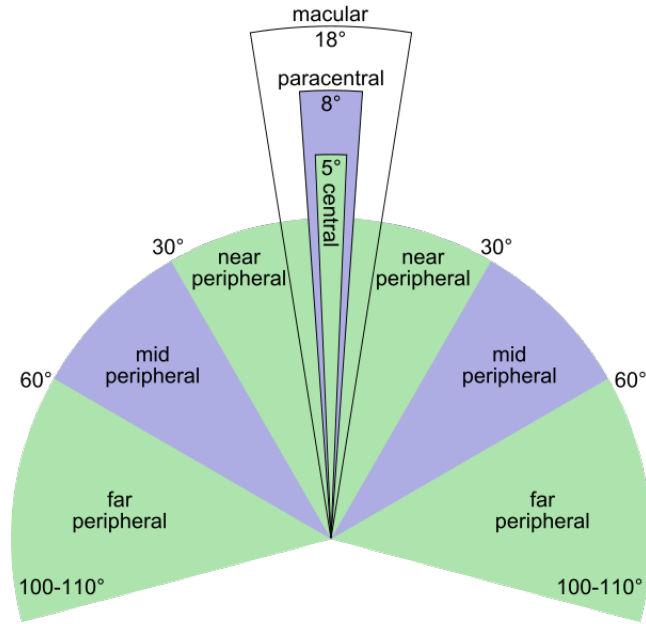
Figure 2.4: Regions in the human visual field. From [108].

Theory (SDT) provides many measures we can use to accurately model a user's ability to separate "signal from noise" [106] (e.g., the ability to correctly detect a visual stimulus intended for user interface notification design that may or not be present). Particularly useful to asses a visual stimulus ability to effectively serve as a peripheral notification is the concept of True Positives, False Positives, False Negatives, and True Negatives (summarized in Fig 2.5) which can be used to model in terms of accuracy, precision, recall or sensitivity.

Detecting a peripheral notification in a user interface may be considered a signal within SDT. The user may either detect (true positive) or fail to detect the signal from the notification (false negative). Conversely, a user may also falsely identify something as a peripheral notification (false positive) or correctly not detect any signal (true negative). Ideally, users would only attend to a stimulus intended as a notification when the stimulus is actually present.

While incorrectly detecting a visual stimulus for a notification is generally harmless and can be generally played down as an "annoyance", there are cases where missing a notification may have undesirable penalties such as missing a critical warning in a control room, or missing critical weather updates in a user's surrounding area. In cases where noticing a notification is critical, precision and recall metrics may be better suited to model the effectiveness of a visual effect for use in a notification.

Stimulus Status

Figure 2.5: Confusion Matrix showing an observers performance on a stimulus detection task. The left column represents cases or trials when a target was present, while the right column represent trials with no target present.

In a categorization task, *Precision* is defined as the number of responses categorized as true positives divided by the total number of true positives predicted (Eq. 2.1) in the task. For peripheral notifications, it lets us model how many of those stimulus categorized as notifications were actual relevant notifications (not noise). Precision is a measure better suited for when the cost of a false positive is high - helpful for avoiding distracting a user. Precision, however, fails to answer whether all relevant stimuli were perceived.

$$Precision = \frac{True\ Positive}{True\ Positive + False\ Positive} \qquad (2.1)$$

To address whether all relevant stimuli were perceived, *recall* is a measure defined as the total number of true positives retrieved divided by the number of positive available (Eq. 2.2). For peripheral notifications, recall would allow us to model how many of the notifications were perceived out of the total notifications presented. Recall is suited for notifications where the cost of a false negative is high (such as missing a critical warning).

$$Recall = \frac{True\ Positive}{True\ Positive + False\ Negative} \qquad (2.2)$$

2.3 Notifications and Distraction

Avoiding distracting or irritating the user during notifications is an important but difficult design task. A poorly timed notification can lead to an unintended distraction with an adverse effect to primary task performance [8, 28] and an altered emotional state on the user [3]. This section summarizes what is known about the effects of distracting interactions on the user, what is known to be distracting, current technical solutions to properly manage gaining user's attention, and user interface notification design.

2.3.1 Notification Design

In large-scale safety-critical systems, such as control rooms and aircraft cockpits, alarms tend to propagate rapidly [106]. Previous research has found that an excess of visual alerts reduces human processing capability due to disturbance and distraction [39, 91, 107]. 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 [30, 14].

Change Blindness is often due to visual disruption [30, 81], and is more likely to occur when change occurs on a stimulus that the user is not focusing on [106]. Inattention Blindness refers to a failure to perceive a stimulus that is in plain sight [92]. Failure to notice stimuli is particularly prevalent when performing repetitive and monotonous tasks.

The effects of change blindness and inattention blindness in mobile devices was explored in work by Davies and Beharee, where they found that increasing the number of items (i.e., icons in a menu) led to participants being less likely to detect a visual change in the interface (such as a flicker effect) [30]. Furthermore, they found that 34.5% of the notifications displayed were completely unnoticed. Davies and Beharee noted, however, that those notifications that were displayed using an "insertion" technique (an icon appearing for three seconds) over a nofication displayed with "gradual changes" (i.e., changing the text of a label) were noticed twice as fast (2034 ms) over gradual change (5317 ms). The authors note the "pop out" effect of the insertion technique as the possible reason for the increased noticeability of the notifications [30].

While current desktop systems blend their notification design with the rest of their user interface design (e.g., notifications in MacOS and Windows10, Fig 2.6), previous research on notification design has proposed a proportionality between stimuli salience and the importance of the content
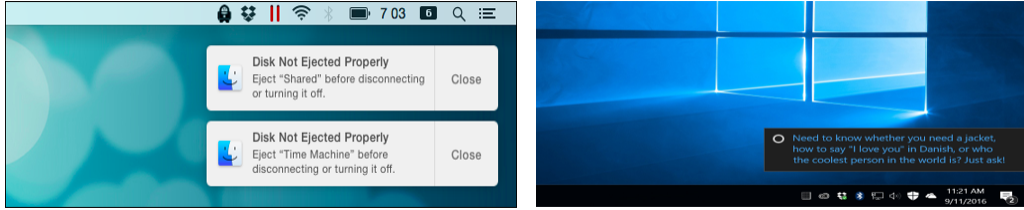
Figure 2.6: Notifications in MacOS and Windows 10.

[65, 82, 40]. Matthews *et al.* suggested five categories of notification salience: ignore, change blind, make aware, interrupt, and demand attention [63].

- Change blind: Notifications with information that is marginally important and should be displayed in a way that causes no cognitive load, they may still, however, affect behavior. These notification should at most be able to be dealt with a divided attention from the user.

- Make Aware: Notifications with information of some importance that require some attention from the user, but are not critical.

- Interrupt and Demand Action: Notifications that require immediate and focused attention from a user. These levels should be reserved for notifications regarding a critical alarm or update. Demand actions should require the user to stop their primary task to attend and stop the notification.

Software notification systems can be developed to show notifications based on the anticipated importance to the user [47]. A system that anticipates the relative importance of a notification can calculate a priority score based on values from data associated to the user. Notifications can then be ranked based on the values and presented to users in an ordered manner through the notification system of their devices [47]. An effective notification ranking based on the relative importance to a user can help mitigate unintended distraction and annoyance effects for users focused on tasks.

Effective intelligent notification systems - systems that determine what information is important as well as the ideal times to interrupt a user, however, must be reliable to be able to gain a user's trust [58]. Specifically, designing notification systems that provide a high level of reliability (by showing only relevant notifications) from the outset from the outset is extremely valuable for a user. LeeTiernan *et al.* found that users that were presented with an unreliable notification system during the first block of an experimental session opened 20% fewer notification through the rest

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of the session - even though the system improved across trials, when compared to those that were presented with a reliable notification system from the start.

2.3.2 Managing Distraction in User Interfaces

Many desktop applications such as email clients, instant messaging, and status updates are competing for user attention, using notifications to let the user know their input is needed. Although these applications do not necessarily intend to distract a user, they do often not consider the impact an unnecessary interruption has on a user, and even the most slight distraction due to a notification has the potential to cause interruption overload.

Several studies suggest that the best times to interrupt users are towards the beginning, middle or end of a task [27, 28]. Miyata and Norman suggest that executing a task is comprised of three main steps: planning, execution, and evaluation [68]. Extending from this idea, each sub-step for a task is also comprised of the three steps, making the execution of a task a loop of these steps. While there are clear negative effects to interrupting users at various steps of a task [118], the three steps can be temporally associated to the beginning middle and end of the execution of a task loop.

Associating a temporal placement (beginning, middle, end) as the best time to interrupt a user may be, however, an oversimplification of task execution. Instead, another suggestion is to interrupt users at task boundaries or breakpoints during a sequence of tasks [7, 3]. Cutrel *et al.* found that users that were interrupted earlier in their tasks were more likely to forget what there primary task was [27]. Bailey *et al.* found that interruptions made during a task, rather than during a task boundary, caused users to take up to 27% more time to complete their task, made twice as many errors, and reported a frustration up to 106% higher than those that were interrupted at task boundaries [7].

Work has been done to compare different methods to decide when to interrupt users working on a primary task. McFarlane studied four interruption methods that required different user input: immediate (required immediate user attention and response), negociated (the user decides when to attend), mediated (the system decides when to interrupt), and scheduled (interruptions are at predetermined intervals) [67]. None of the methods was found to be a clear best way to decide when to interrupt a user; however, it was found that users that were forcibly required to attend to the distraction were less efficient in their primary task but completed their distracting task promptly, while users that were able to choose when to attend to the distraction had a higher performance on their task [67].

Researchers have noted a variety of characteristics that make interruptions most disruptive for users working on primary tasks. Some of these characteristics include a high number of frequent interruptions [118, 95], the similarity between the interruption and the primary task [38], and the complexity of the interruption [38]. The length of the interruption, however, has not always been found a significant way to measure how disruptive an interruption is. Some shorter disruptions, specifically ones that are more similar to the task, can be found more disruptive than longer interruptions [38].

As interruptions become more frequent in work-spaces and desktop environments, methods for recovering a user's focus back to their primary task after an interruption have been studied. A study by Renaud showed that providing a visualization of application activity helped users recover more rapidly and efficiently from interruptions [80]. Hess and Detweiler found that allowing participates to train on the primary task with interruptions for two sessions found subsequent sessions with interruptions significantly less disruptive.[49].

Ware studied the use of moving icons for notifications, finding it effective and less irritating than other effects such as blinking and flashing [107]. Motion effects could be an effective way to draw users attention due to their high visibility throughout the human visual field, while other effects such as color or shape have been shown to decrease as visual angle increases [42]. The effects of combining effects such as color and motion, as well as their suitability for notification design in large displays has not been addressed yet. Making users aware of changes in unattended displays is a significant challenge, as research has outlined the phenomenon of change blindness as a factor that affects noticeability [32].

Gaze-Contingent Displays - displays that manage the display of visual information through real-time eye movement sensing can be effective to manage attention and distraction in user interfaces [79]. Several suitable visual effects for notification design for gaze-contingent displays have been explored such as size, opacity, blink, and movement. A study by Klauk *et al.* found high levels of distraction for blink and motion visual effects to users regardless of their noticeability, and proposed opacity as the most suitable visual effect for subtle notifications [55]. Other technical solutions for subtle notification design include the use of wearables to display information to the wearer. Eye-q, a wearable peripheral display in eyeglasses, for example, used peripheral LEDs to deliver discreet notifications to users [26].

2.3.3 Design Considerations for Multiple-Display Environments

For many years, multiple-display environments were mostly utilized in collaborative settings used by multiple people at a time including control rooms, trading floors, and airplane cockpits. There is a recent trend, however, for multiple display environments to be used in more traditional office and home desktop workspaces. The benefits of having larger-multiple display environments have been extensively studied, showing improvements in areas including office productivity tasks [29], and data visualization [9, 10], as they provide a larger physical display area, allowing for more information to be presented at a time [11].

New design considerations, however, have to be taken into account when designing for large displays. Researchers have already addressed concerns about display bezels (common in multiple-screen setups) effects on performance, finding very limited-to-no effects of display bezels [105, 42]. Furthermore, in large displays, most of the content will be in the user's periphery, where notification can be difficult to notice [37]. Bartram *et al.* previously studied notifications designed for large displays, with their results suggesting that icons with simple motion effects are more effective for driving attention to notifications, while causing fewer interruptions and distractions notifications with color and shape [12].

A main concern of using multiple displays for a computing environment is the effects that physical discontinuity, particularly created by the physical bezels of the displays introduce to task performance. A study by Tan *et al.* found small detrimental effects to performance associated by dividing information across the visual field, but only when further separated by depth - and found no effects of physical discontinuities from display bezels on task performance [98]. The effects if bezel has also been found to have no effects on target search performance [105]. Both findings suggests that designers can afford to have more freedom when designing environments that can span multiple displays.

As large displays have become more prevalent in many settings, researchers have articulated the benefits of working with larger displays for individual users and in group settings. Tang *et al.* studied how display size affects performance on reading comprehension tasks and spatial orientation [99]. While a larger display size was found to not offer any advantage in reading comprehension tasks, users performed approximately 26% better in a spatial orientation task when working in the larger display [99].

Patrick *et al.* evaluated user's ability to form spatial knowledge of virtual environments, compar-

ing a standard desktop display, a head mounted display, and a large projection screen [76]. A large projection screen was found to offer a performance similar to that of the head mounted display, and significantly better than the standard desktop display - with the authors suggesting that the larger size of the display attributed to a higher level of presence, compensating for the immersion factor of a head mounted display [76]. This work suggests that larger displays and projection screens can be used as a (cheaper) alternative to head mounted displays for virtual environments.

When designing user interfaces for multiple displays, one key area of interest has been developing interactive technologies that often rely on a combination of information or functions that are delivered from a device or the internet. When users rely on content that is not delivered locally, many opportunities for obstruction arise (such as network lag). Therefore, there is a need to develop technologies for providing content for for MDEs that efficiently interacts with other services or applications, particularly as these technologies are used often for collaborative environments.

A method for efficiently delivering content for multiple display environments was developed by Steeves *et al.*, one in which a display manager, atleast partly ensures that content is delivered to the first display [96]. Following the presentation of content to the first display, if the display manager encounters problems gathering the content for the following displays, or content is unavailable, the display manager would select a content based on the current content displayed on the first display [96].

Access and data management of information dispersed across multiple devices is often a major problem for users working with multiple display environments [24]. Nacenta *et al.* investigated which interaction techniques can be effective for object movement and information sharing in MDEs. Spatially aware interactions in user interfaces have been found to be useful for users to transfer data across devices, allowing users to maintain focus on the material being handled and enabling analysis and sharing of information [71].

Despite extensive prior research from vision science to understand how we perceive visual effects, efforts to understand how these effects affect user performance in interactive systems, and current advances on developing systems for large displays, 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 chapters, we set out to determine the effects of various combinations of popout effects as an effective way to draw attention in interactive systems, while taking into consideration their unintended distraction effects.

A DESIGN FRAMEWORK FOR PERIPHERAL NOTIFICATIONS AND SYSTEMS FOR EXPERIMENTAL EVALUATIONS

3.1 A Design Framework for Peripheral Notifications

Several design qualities can be identified as desirable characteristics for peripheral notifications. All of these qualities can be adapted to the domain they will be used (e.g., wall displays, MDEs, smart glasses). Therefore, the framework states five basic design qualities that form the endpoints and goals of the design space for peripheral notifications:

3.1.1 Salience and Visual Representation

Visual representation refers to the specific visual features used to encode peripheral notifications. Similar to information visualization problems, designers are presented with a variety of perceptual and visual channels that can be used to develop and communicate different types notifications [70]. Good peripheral notification design promotes a rapid detection of the notifications, a crucial aspect for scenarios such as notifications in control rooms. In the studies presented in this thesis we explore how users perceive individual visual features and their combinations.

3.1.2 Unobtrusive Notification Placement

Peripheral notification placement must be done carefully. In desktop interfaces, notifications are usually shown towards the edges of the display, away from a user's central vision (which the user tends to direct to their main task within the desktop environment). While users can learn to manage a larger number of incoming notifications, these can become distracting and be overwhelming. Notifications should be designed in a way that will not interfere with a user's main task, primarily, their placement should not cover the user's main task. A notification's size should also be controlled, as larger notification sizes can easily occlude the content the user is attending to. A responsive
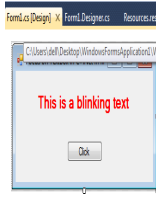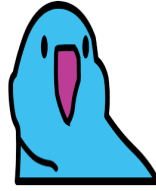
Figure 3.1: HTML blink

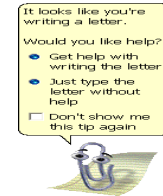**Figure 3.2:** Slack's party parrot

Figure 3.3: Microsoft's Clippy

notification system should also consider whether a visual notification will be distracting given the content the user is focusing on, can adjust the notification size or placement given the main task's content and size, and can decide to employ a different kind of cue all together (such as auditory). Furthermore, with some eye-tracking devices being commercially available and affordable for the general public (such as Tobii 4C Eye Tracker), gaze aware notifications can be developed. With gaze-aware notifications, the visual effect of the notification and its placement can be dynamically adjusted based on the user's gaze.

3.1.3 Non-distracting

Constant connectivity through email and instant messaging is common, however, constant interruptions can easily become annoying, disruptive and in some circumstances even dangerous [27, 3]. Designers should aim to develop interfaces that presents notifications in a subtle and non-obtrusive way that would enable users to make the decision if and how to react to incoming notification.

Many notifications available in current systems are known distracting and annoying for users. Their design characteristics usually include flashing colors (e.g., html blink tag, Fig 3.1), excessive movement (e.g., Slack's party parrot, Fig 3.2). Although now deprecated, Microsoft's Office Assistant, Clippy, was known to pop up while users worked in with advice on how to use the application - which many found unnecessary and distracting (Fig 3.3).

3.1.4 Content-Aware

An unnecessary notification can have a negative effect on a user's task performance [3], designers should minimize the disruptive effect of notifications. While most users want to receive notifications [44], it would be ideal to interrupt users only when they are not focused on their main activities. A notification system can classify incoming alerts by level of priority or importance; furthermore the

Figure 3.4: Study system in a triple-monitor setting.

notification system can be designed to map these to "levels of disruption", making less important notifications use less distracting visual effects. The second study presented in this thesis aims to study the distraction effects of different visual features when used as peripheral notifications.

3.1.5 Consistent Notifications

While users can learn to recognize and understand a large number of visual cues attached to notifications from different applications, attending to many different notification styles can easily become overwhelming for users. A consistent design of notifications - one where all notifications from different applications follow the same design guidelines as the overall operating system (such as colour, font, size), and where notifications from similar apps are grouped together is likely to mitigate unintended distraction effects caused by dynamically changing the visual styles of notifications. The different visual representations from app notifications should be kept at a manageable minimum, and be made consistent for users.

3.2 Systems for Evaluating Visual Features for Peripheral Notifications

To explore the design space above, we built a system that tests three different visual variables for peripheral notifications. Our custom software was made using the Processing language, is adapted to be used in wide screen settings (Fig 3.4), and allows us to control the presentation of stimuli. The stimuli used in the present studies are an approximation to the basic features notifications in user interfaces, as the low-level visual features we test (color, motion, shape) are all common features designers use to implement notifications.

3.2.1 Visual Variables

Following the results from previous studies [42], we implemented color, shape, and motion stimuli in our system as these would provide varied noticeability across their different levels of intensity across the human visual field. This would allow us to see whether combining the 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 3.5. 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. A black background was used for all object presentations.

3.2.2 Design of the System

In designing a system to evaluate how users perceive visual features, there were several requirements that needed to be met. First, we were concerned about repeatability - each participant should be presented to the exact conditions as all the other participants. Second, we were concerned about learning effects, i.e., where participants get better at detecting visual effects as the study progresses. Third, we needed to detect whether participants were in fact answering to the best of their abilities, rather than guessing.

To meet the requirement of repeatability, we designed all visual variables with pre-determined values that allowed our participants to experience all variable and intensity level combinations equally. To further ensure repeatability, the study's user interface remained unchanged for every participant. When the study started, participants first saw a screen to input the participant number (Fig 3.6), which the experimenter completed for the given participant. After the participant number was entered, the experimenter would then select the appropriate visual variable to present from the menu screen (Fig 3.7), given the counter-balanced order. By having the option to select the presentation order for our visual variables, we are able to meet our second requirement of preventing a learning effect.

After selecting the visual variable, participants were shown the instruction screen (Fig 3.8), that presented the main experimental task for the study and provided examples of the visual variable and the distractors. After the participant pressed the space key to begin the trials, each trial began with the presentation of a fixation cross (Fig 3.9), after which visual stimuli were presented for 240ms (Fig 3.10). After each trial concluded, participants were shown with a screen to enter their response to the trial task (Fig 3.11). After the response had been recorded, a new trial began with

	D	1	2	3	4	5
Color (RGB)	(0,0,250)	(29,0,200)	(58,0,150)	(88,0,100)	(117,0,50)	(146,0,0)
Shape (line width)	50	41	32	23	14	5
Motion (move/frame)	0px	1px	2px	2px	2px	2px
Color + Shape (RGB) (line width)	(0,0,250) 50	(29,0,200) 41	(58,0,150) 32	(88,0,100) 23	(117,0,50) 14	(146,0,0) 5
Color + Motion (RGB) + (move/frame)	(0,0,250) 0px	(29,0,200) 1px	(58,0,150) 2px	(88,0,100) 2px	(117,0,50) 2px	(146,0,0) 2px
Motion+ Shape (move/frame) + (Line Width)	50 0px	41 1px	32 2px	23 2px	14 2px	5 2px
Shape + Color + Motion (Line width) + (RGB) + (move/frame)	50 (0,0,250) 0px	41 (29,0,200) 1px	32 (58,0,150) 2px	23 (88,0,100) 2px	14 (117,0,50) 2px	5 (146,0,0) 2px

Figure 3.5: Distractor (D), Visual Variables and Intensity Levels (1-5, and value for level). Note: Motion is capped at 2 when combined.

Figure 3.6: Participant Selection Screen
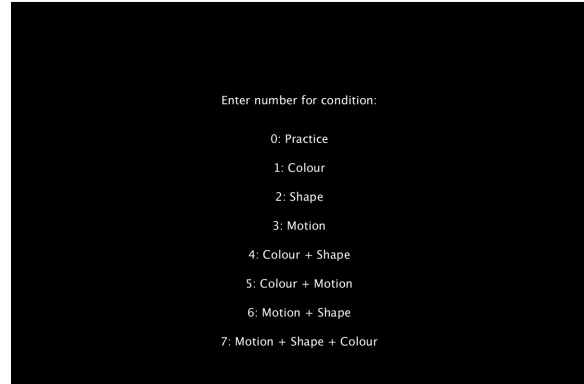
Figure 3.7: Visual Variable Selection Screen

the presentation of the fixation cross.

Finally, to be able to prevent participants from guessing in every trial, we experimentally controlled the trials where the visual variable was present. In accordance to Webber's Law of Just Noticeable Differences [34], a stimulus intensity (or its presence in trials in our case), must be changed to elicit a noticeable variation in a subject's sensory experience. A 60/40 split in target's presence in trials was chosen to maximize the number of trials containing the target without participants realizing that there were more of one type. We also accounted for anticipatory action on every trial: the presentation of the fixation cross on screen was set to be at a random interval between 1-2 seconds before each trial.

3.2.3 Technical Implementation

The system was implemented using desktop-based technologies so it could be easily adapted to multiple display environments and varying screen sizes. The system was built as a processing Application (https://processing.org/), using Processing 3.4. All participant data logging was done through the system and was stored in the local computer in a .txt file.

All visual variables were generated through simple Processing 2D shapes, with custom specifications to present each variable's different intensity levels:

- *Color:* Distractors and targets were circles of 50px in diameter drawn with the `ellipse()` function (Fig 3.5). Target hues were equally spaced in RGB from distractors in values of "red" and "blue". Blue distractors were RGB(0,0,256) and the target was RGB(146,0,0) at the red end of the scale.

28
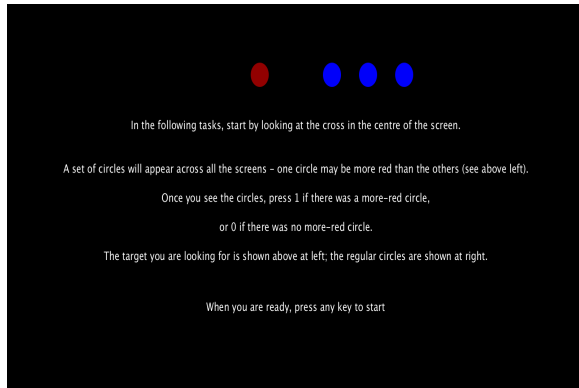
Figure 3.8: Instructions Screen After Selecting a Visual Variable
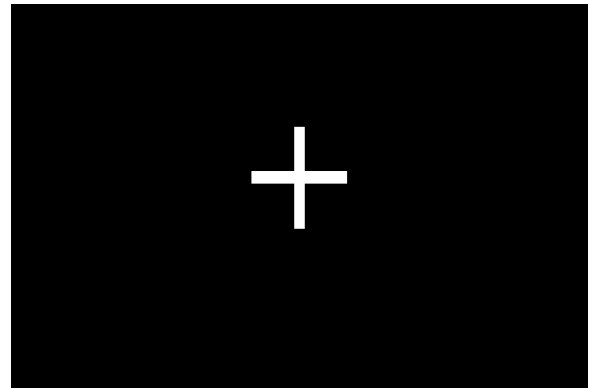
Figure 3.9: Cross-hair Screen before each experimental trial
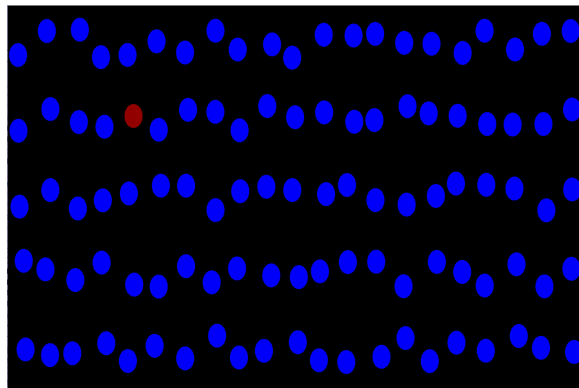
Figure 3.10: Example Trial Screen for Color Variable (Scaled down to single screen)
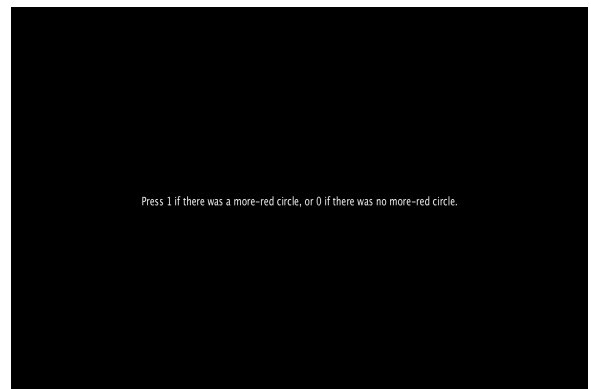
Figure 3.11: Response Selection Screen

- *Shape:* Distractors were 50px blue squares. Our target's shape deviated from the square distractors by the amount of intrusion at each corner, effectively becoming a cross (Fig 3.5). Targets were drawn with the `line()` function which allowed us to draw a lines in the screen. By default, Processing draws 2D lines with a width of one pixel; We changed line width (degree of intrusion) in increments of 9 pixels for the different intensity levels using the `strokeWeight()` function.

- *Motion:* Distractors were 50px blue squares. Our targets' 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 (Fig 3.5). Target squares were drawn with the `rect()` function which allowed us to draw a square by setting equal width and height.

3.3   Adaptations to the System: Incorporation of a Primary Task

For our second study, we evaluate the noticeability and distraction of visual variables when users attend a primary task. The study software described in the previous section was developed so that a main task component can be easily added. Most of the study software remained unchanged or included slight modifications, including participant selection (unchanged), instructions screen (Visual variable options change to show only two of the visual variables, Fig 3.12), and instructions (accommodates description needed for snake game, Fig 3.13). A main task component, however, was added, introducing the Snake game (Fig 3.14), and removing the need for the fixation cross screen and the response selection screen (as participants now press '1' if they detect the visual variable during the game). The main task of the Snake game involves maneuvering the snake, avoiding obstacles to eat an "apple" which allows the snake to grow in length. The presentation of the visual variables remained unchanged.

The snake was drawn using the Processing `rect()` method, which specifies a small square for each section of the snake (head, tail, and body sections). Each time the participant successfully ate an "apple" (which was detected through a collision detection algorithm, detecting when the snake's head came in contact with the apple) a section was added to the snake, making the snake longer. Further collision detection was added to the gameplay by incorporating invisible rectangles on the edge of the screen (where going off-screen would cause the snake to die). A *score* counter was added, which would allow us to investigate a participant's game performance given the presentation of a particular visual variable.
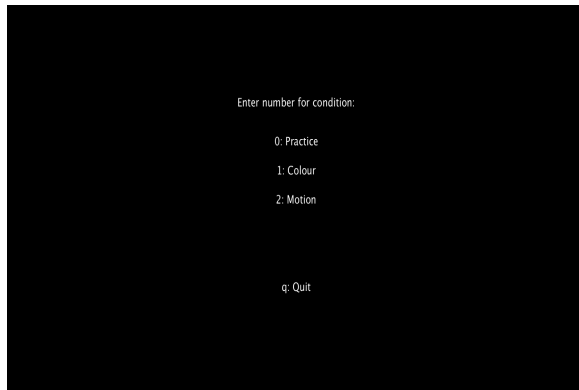
Figure 3.12: Visual variable option screen for study 2.
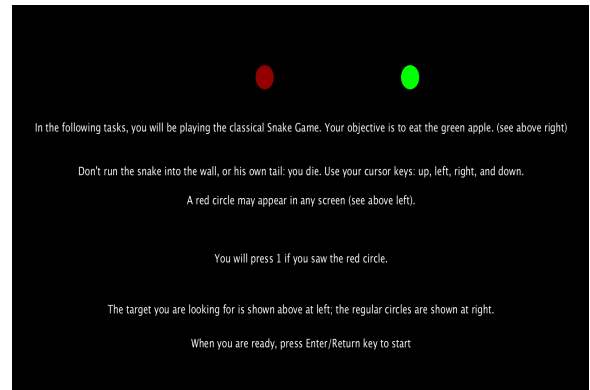
Figure 3.13: Experimental tasks instructions for study 2.
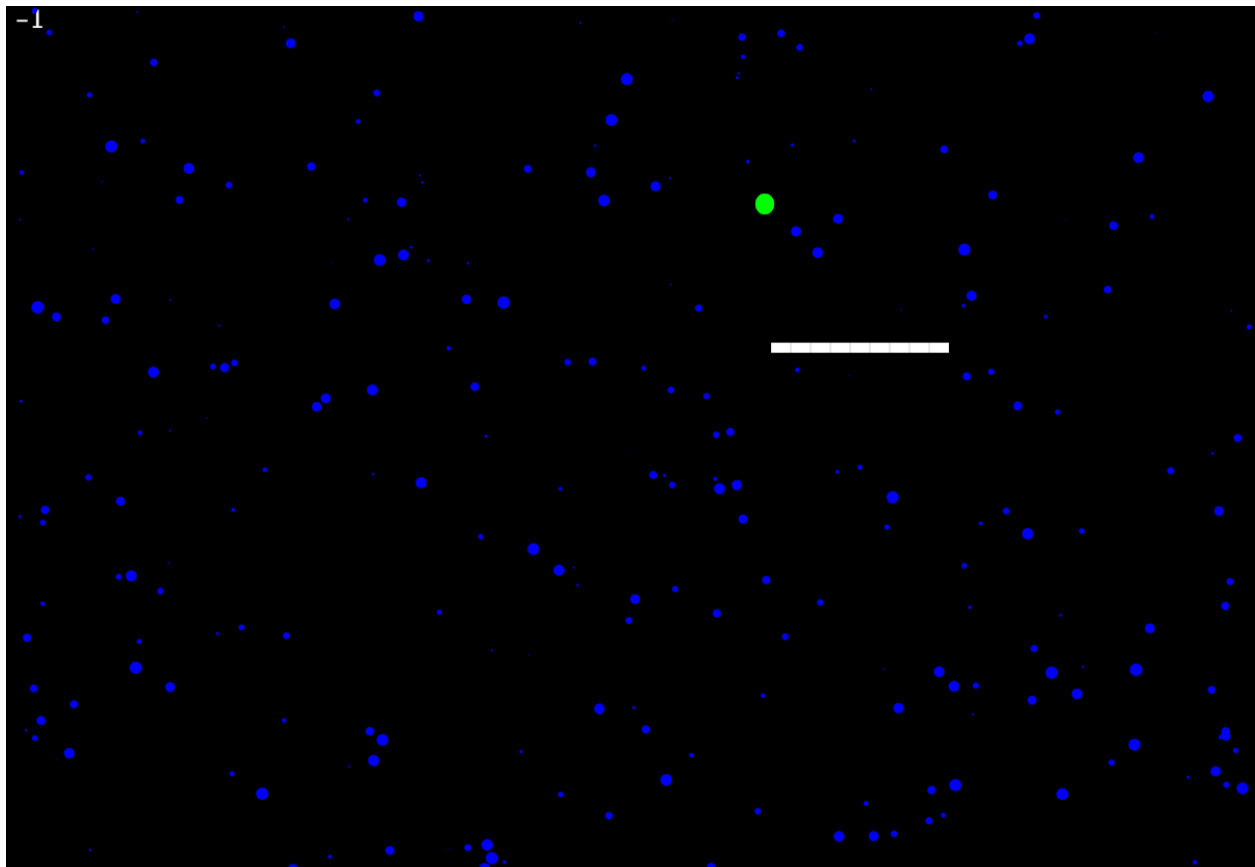
Figure 3.14: Gameplay capture from experimental trial. Snake (white line) maneuvering obstacles (blue circles) to eat an apple (green circle).

3.4 Summary

In this chapter we introduced a design framework for peripheral notifications which emphasizes the need to develop notifications that can easily be detected by users while keeping distraction effects at a minimum. In Chapter 4, we provide details of a study evaluating combinations of visual features for enhanced noticeability to peripheral notifications. In Chapter 5 we then evaluate the noticeability and distraction of visual features when used as peripheral notifications while the user attends to a primary task.

Chapter 4

Additive Effects of Visual Stimuli

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. Combining visual features (e.g., color and motion) is a common design approach for improving noticeability. The first study of this thesis was designed with the goal of answering the question: What are the effects of combining visual features on peripheral noticeability? The system described in Chapter 3.2.2 was used to answer this question. The results of this study provide a measure of people's accuracy when perceiving visual effects.

4.1 Participants and Recruitment

Twenty-one participants were recruited from the local university community (8 male, 13 female) through the University of Saskatchewans online bulletin board and were given an honorarium of $20. All participants were students and ranged in age from 20 - 42 years. The average age of the participants was 25 years (SD 4.4). Participants reported normal or corrected-to-normal vision and no diagnosis or history of color-vision deficiencies. All participants were experienced with mouse-and-windows desktop application (10 hrs/wk).

4.2 Apparatus

The study used a three-monitor setup with three Asus 27-inch UHD LCD panels (Figure 6.1) 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 Windows10 PC. We built a custom experimental system in Processing for the study
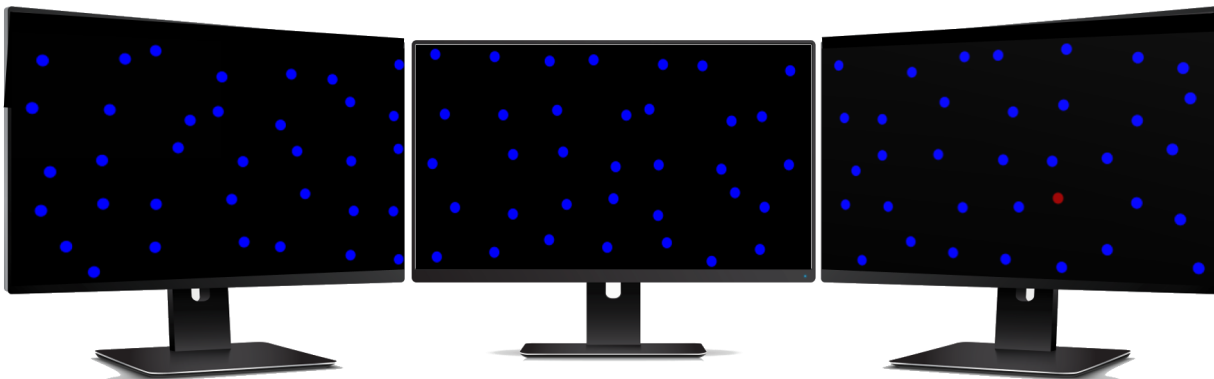
Figure 4.1: Visual field for a trial

that presented all trials (in full-screen mode) and recorded performance data. All questionnaire data was collected through web-based forms.

4.3 Visual Angles

For consistency and comparison, we presented our visual variables in the same angles as those of Gutwin *et al.* [42]. Six horizontal target locations were chosen (duplicated for left and right); three angles covering the near peripheral region ($\pm 6°$, $\pm 18°$, and $\pm 26°$), and three cover the mid-peripheral region ($\pm 38°$, $\pm 50°$, and $\pm 62°$). Angles were measured from the center vertical line. We placed targets at $\pm 8°$ from the center horizontal (upper and lower locations were collapsed for analysis).

4.4 Tasks

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.

Figure 4.2: Distractor (D), Visual Variables and Intensity Levels (1-5, and value for level) for Study 1. Note: Motion is capped at 2 when combined.

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 6.1). 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 (Fig 4.2) was shown in 60% of trials [42].

4.5 Procedure

Each study session involved a single participant at a time. The session procedure had three major steps: an informed consent and pre-study questionnaire stage, a practice stage, an evaluation stage, and a debriefing phase.

1. **Pre-Study Questionnaire:** This questionnaire was used to gather personal information each participant. Personal information included age, gender, occupation, education level, computer experience (hours per week), previous diagnosis of colour blindness, and previous diagnosis of peripheral vision deficiency.

2. **Practice Stage:** The participant performed trials of the study using a different visual variable (flashing) to ensure they were confident in their understanding of the expectations from the task. The program was then stopped and restarted and no results were recorded from this step.

3. **Evaluation Stage:** After the completion of the practice stage, participants 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. After completing all the intensity levels of a visual variable, participants completed a NASA-TLX subjective workload questionnaire [45] and proceeded to the next visual variable.

4. **Debriefing Stage:** After the completion of all experimental trials for all visual variables, participants were debriefed about the experiment, and were encouraged to ask any questions. Payment towards the participant was done at this stage.

4.6 Study Design and Analysis

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

- *Visual Angle*: The horizontal angle our variables were presented ($\pm 6°$, $\pm 18°$, $\pm 26°$ $\pm 38°$, $\pm 50°$, and $\pm 62°$).

- *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 3.5). The study used five levels of intensity for our visual variables.

Responses to the TLX-style questionnaire were also analyzed.

4.7 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% (shown in Fig 4.3), suggesting participants answered honestly throughout the experimental conditions.

4.8 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 $\pm 6°$ from the center to less than 20% at $\pm 62°$ (Figure 4.4). 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 $\rightarrow$ Color+Shape, and Motion+Shape $\rightarrow$ 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.

4.9 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 ($F_{24,432} =$

37
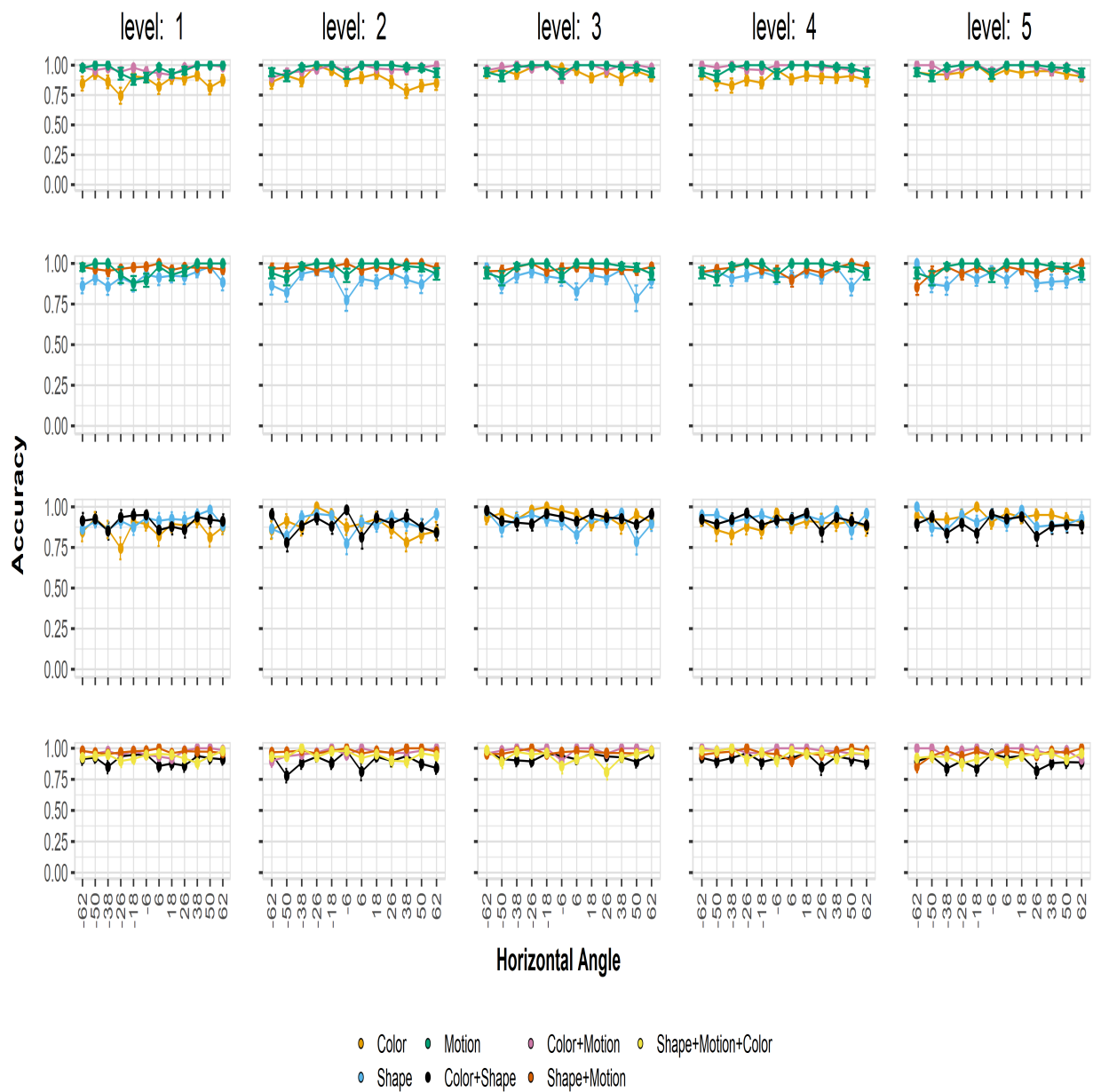
Figure 4.3: Data Check: Accuracy (±s.e.) on trials with no target only, by Variable (rows), Intensity Level (columns), and Angle (x-axis).
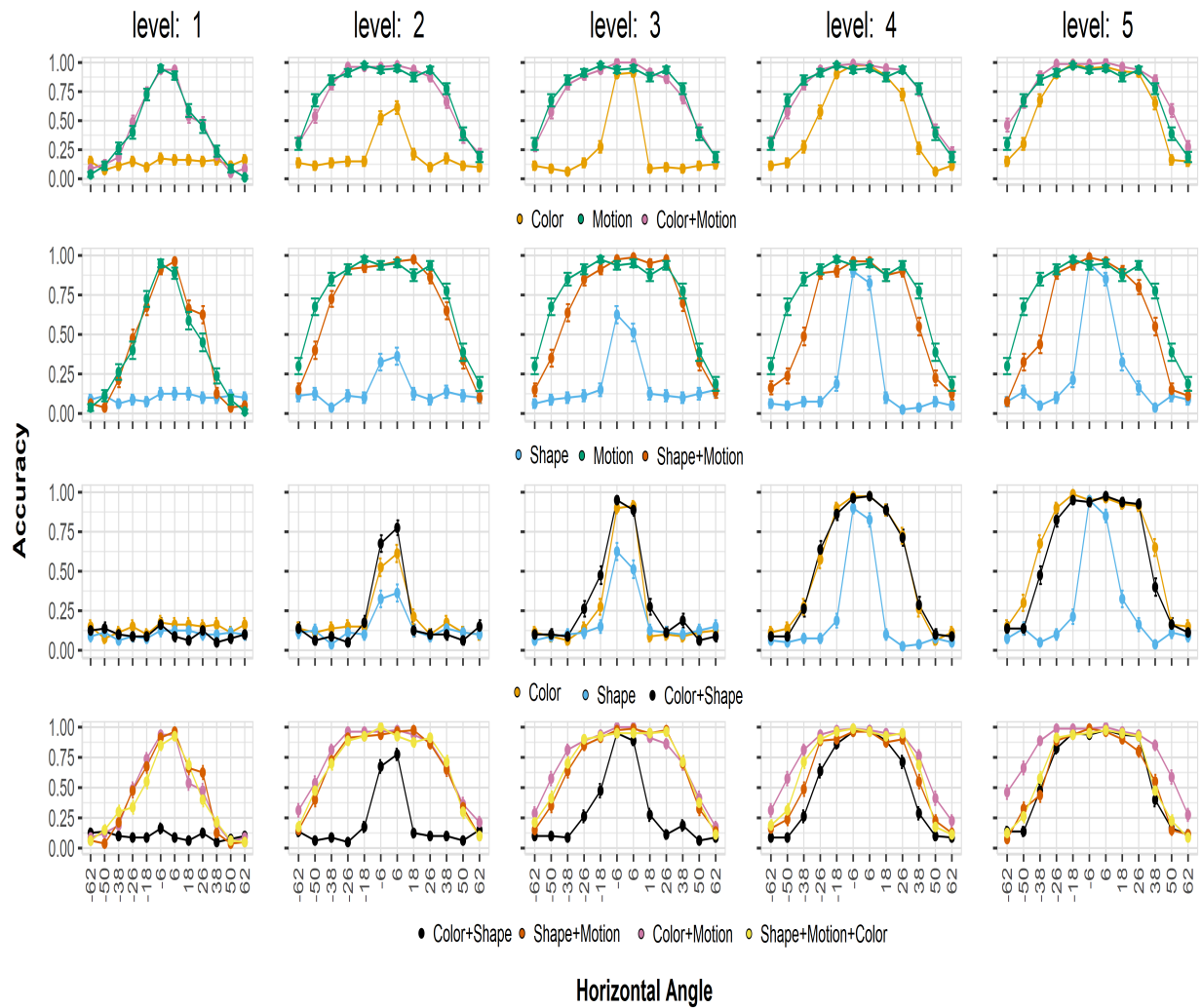
Figure 4.4: Accuracy (±s.e.) by Variable (rows), Intensity Level (columns), and Angle (x-axis). Target-present trials only.

$29.41, p < 0.0001$); 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 4.4. 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.

4.10 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 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%).

4.11 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 4.5. 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).
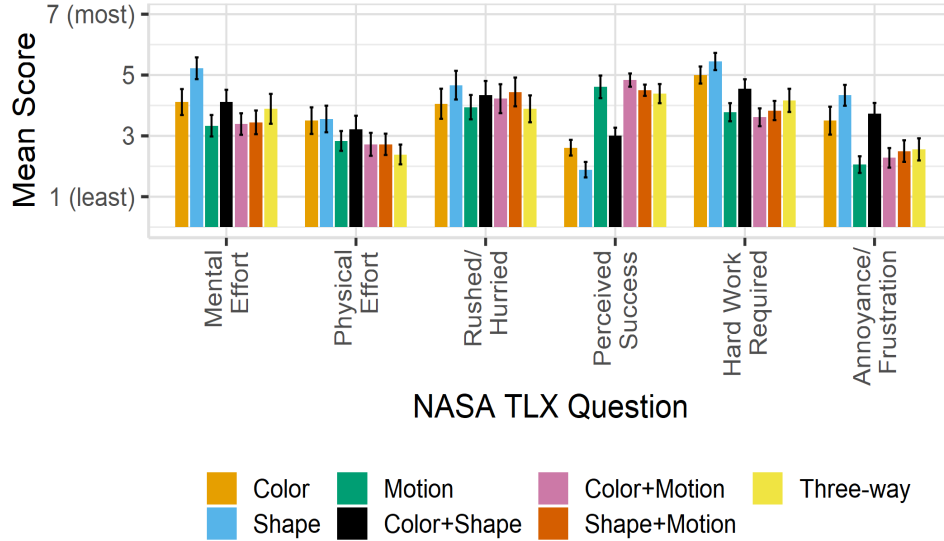
Figure 4.5: Mean NASA-TLX questions responses (±s.e.).

4.12   Summary

With Study 1, we had one goal: determining what are the effects of combining visual features on peripheral noticeability. We achieved the our goal by gathering information on participant's accuracy on detecting visual stimuli at many angles.

Specifically, we designed a system that presented individual visual variables (e.g., color, shape, motion) and their combinations at various angles and intensity levels. Participants were asked to state whether they saw a particular visual variable for each intensity level at a given angle in their visual field. In analyzing the data, we focused on the accuracy on trials were there was a target present and found that combining visual variables does not offer an improvement in accuracy when compared to the accuracy of a single variable. Accuracy generally follows the performance of the better of the visual variables - where motion was generally found to be as the easiest to detect.

Our subjective TLX-style questionnaire provides further evidence that combining visual variables offers no improvement over using a single variable. Similar to our quantitative data, participants noted that motion was the easiest to detect, while shape was the visual variable that required the most effort to detect.

In summary, we have presented evidence for this research to continue under the assumption that combinations of motion, color, or shape do not offer an improvement over utilizing a visual variable on its own. In the next chapter, we now focus on participant's accuracy on detecting visual

variables when they focus on a primary task. We also implement methods to measure any unintended distraction caused by these visual variables intended to be used as peripheral notifications.

Chapter 5

Popout and Distraction with a Primary Task

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. This study described below is designed to answer two questions: first, how does the noticeability of a visual effect change when a users focuses on a primary task; second, what are the distraction effects caused by visual stimuli when used peripheral notifications. We designed our study following a similar method to Study 1, but with the following adjustments.

5.1 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 ($\pm6°$, $\pm18°$, and $\pm26°$) 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. Removing the central angles also prevents unintended and unnecessary annoyance our participants may have experienced with notifications appearing in the centre of their primary task.

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. This score variable increased by one everytime the participant completed a game objective (in the Snake game's case: every time participants ate the green apple).

5.2   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 and no diagnosis or history of color-vision deficiencies. All participants were experienced with mouse-and-windows desktop application (10 hrs/wk).

5.3   Apparatus

The study used a three-monitor setup with three Asus 27-inch UHD LCD panels (Figure 5.1) 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 Windows10 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.

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 (e.g., 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, which were presented relative to the snake's head position in the game.
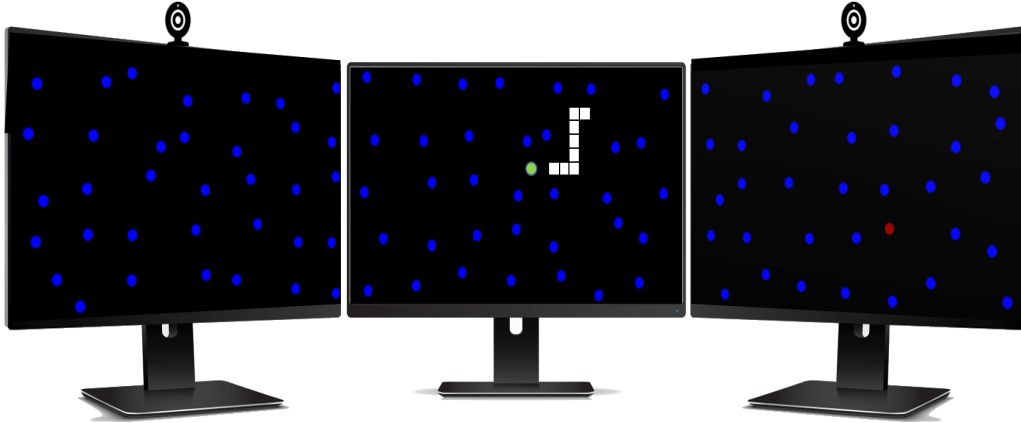
Figure 5.1: Experimental setup for Snake Game

5.4 Main Task: Snake Game

The main task of our second system was based on the arcade game *Snake* (Figure 5.1). Participants maneuvered a line (the snake) which grew in length after eating each target (a green block representing an apple), with the line itself being a primary obstacle. We also added distractors (similar to the ones in Study 1) distributed randomly across the three screens, which also moved down the screen, giving the illusion that they were falling stars. The distractors also served as obstacles, with a one point score deduction if the snake hit an obstacle. Participants used the arrow keys to move the snake and had to press '1' when they saw a stimuli (the system did not pause as it did in Study 1). Participants had to respond within one second of the stimuli for their response to be recorded as correct.

5.5 Procedure

Each study session involved a single participant at a time. The session procedure had three major steps: an informed consent and pre-study questionnaire stage, a practice stage and evaluation stage, and a debriefing phase.

1. **Pre-Study Questionnaire:** This questionnaire was used to gather personal information each participant. Personal information included age, gender, occupation, education level, computer experience (hours per week), previous diagnosis of colour blindness, and previous diagnosis of

peripheral vision deficiency.

2. **Practice Stage:** The participant performed trials of the study using a different visual variable (flashing) to ensure they were confident in their understanding of the expectations from the task. The program was then stopped and restarted and no results were recorded from this step.

3. **Evaluation Stage:** After the completion of the practice stage, participans were then assigned to a random order of presentation of the visual variables (color, motion, color+shape). Participants carried out a series of trials for each intensity level of the first visual variable, in order from most intense to least intense. After completing all the intensity levels of a visual variable, participants completed a NASA-TLX subjective workload questionnaire [45] and proceeded to the next visual variable.

4. **Exit Questionnaire:** After the completion of all experimental trials for all visual variables participants completed an exit questionnaire. Information gathered at this stage includes participants perception of distraction for each visual variable, which variable they thought was most noticeable, and whether a variable hampered their game performance.

5. **Debriefing Stage:** After the completion of the exit preference questionnaire, participants were debriefed about the experiment, and were encouraged to ask any questions. Payment towards the participant was done at this stage.

5.6 Study Design and Analysis

To measure the peripheral noticeability of popout effects in an applied setting, 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 ($\pm 62°$, $\pm 50°$, and $\pm 38°$) calculated from the location the participant is looking at (based on snake head, and checked with webcam feed).

- *Level*: Intensity level (same as study 1).

To measure the distraction of the different popout effects, the game score acted as dependent measure, with variable, angle, and level as factors (all within-subjects).
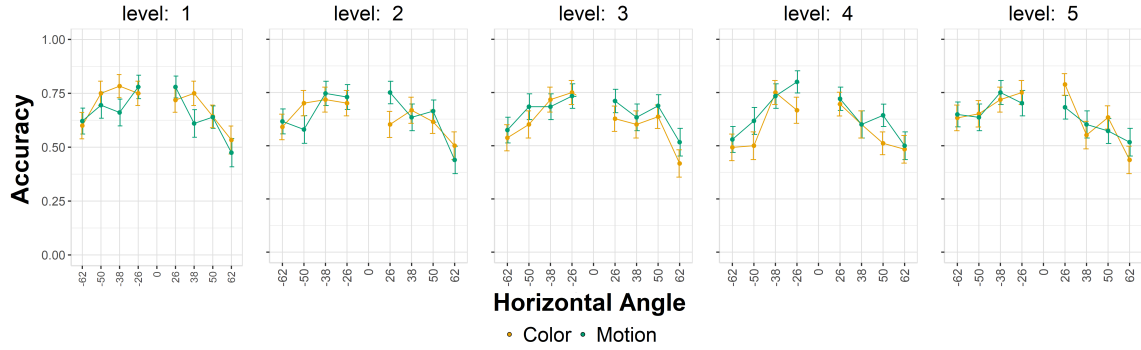
Figure 5.2: Accuracy (±s.e.) by Variable (rows), Intensity Level (columns), and Angle (x-axis) in Snake.

5.7 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 and we can analyze all trials as a rough approximation of users in a normal, every-day setting.

5.8 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 5.2. 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 ($F_{28,532} = 0.92, p = 0.57$).

5.9 Score: Main Effects of Angle, Variable, and Level

One of the main tasks of the game was to eat a green apple to help the snake grow. Each time a participant ate an apple with the snake, their score increased by one. 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 5.3), even though it was noticed at approximately the same rate as our color cue. 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 ($F_{28,532} = 0.91, p = 0.59$).

5.10 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* ($F_{1,19} = 0.02, p = 0.66$).

5.11 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 5.1. 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 5.2), and their reasoning behind the answers.

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
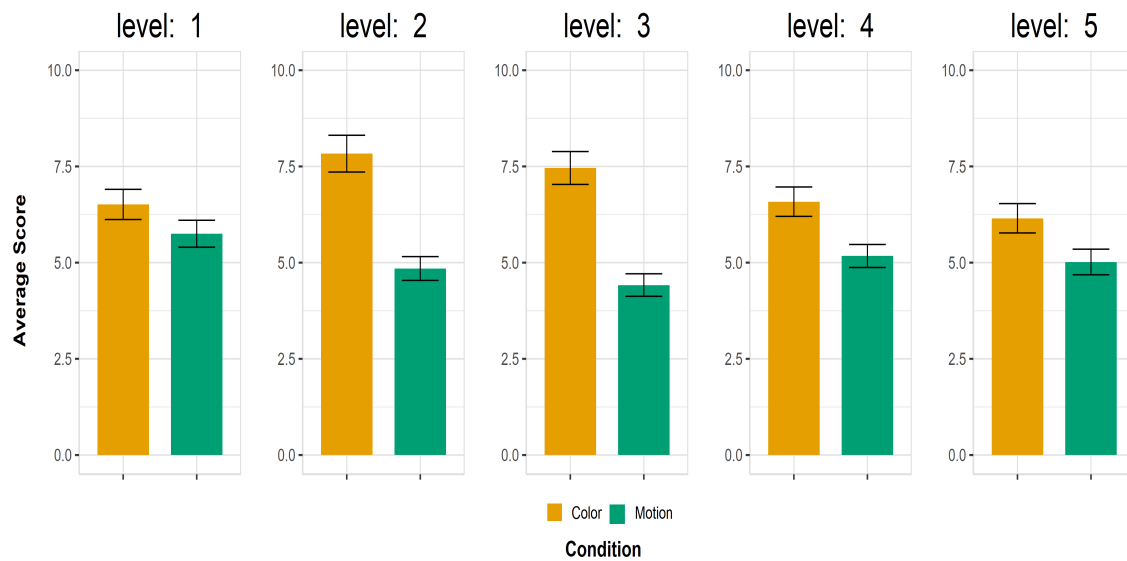
Figure 5.3: Game score during presentation of visual variable.

	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 5.1: 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 5.2: Participant Preference.

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."

5.12   Summary

With Study 2, we had two main goals: First, determining how peripheral noticeability of visual features changes when a user is focused on a primary task comprised of many other visual effects - similar to an every day user interface. We achieved the our goal by gathering information on participant's accuracy on detecting visual stimuli when they played a modified version of the game Snake [1]. Second, we aimed to measure the distraction effects peripheral notifications may have, affecting primary task performance.

Specifically, we designed a system that presented a subset of the same individual visual variables (e.g., color and motion) studied in study 1 while users focused on a primary task consisting of playing the classic arcade game Snake. Participants were asked to react by pressing '1' when they saw a particular visual variable for each intensity level at a given angle in their visual field. The angles the visual variables were dynamically allocated based on the user's gaze position. In analyzing the data we found that the visual effects of the primary task may cause an interference to the visual variables we presented intended to be used as peripheral notifications. The saliency of the motion effect decreased in study 2; we hypothesize that it may be due to the fact that the primary task was heavily comprised of other moving targets and components.

Furthermore, our measures of distraction (the game score) provided insights on how the visual effects of motion and color affect users. Even though both visual variables were found to be similar

in performance, motion was found to have a clear negative effect on game performance across all intensity levels.

Our subjective TLX-style questionnaire provides further evidence for the decreased performance of the motion variable. While motion remained the easiest to detect, participants noted no difference in any other subjective measure between both color and motion visual variables - contrasting study 1, where motion was found to be vastly superior.

In summary, evidence has been presented for this research to continue under the suggestion that the visual effects of a primary task may cause an interference in the noticeability of peripheral notifications. Second, some visual variables such as motion may be more distracting to primary tasks. In the next chapter, we now describe a preliminary follow-up study focusing participant's accuracy on detecting visual variables with an increased presentation time. So far, we have presented our visual variables for 240ms; in the following chapter we have doubled the presentation time to measure any differences in noticeability.

Chapter 6

Preliminary Study: Increased presentation time

The two studies described above presented the visual stimulus for 240ms, exploring the effects of instantaneous noticeability. However, in most real-word interfaces, notifications will remain visible to users for longer than 240ms. This raised the question whether there is a relationship between presentation time and popout stimuli noticeably.

To provide some preliminary insights on presentation time and noticeability, we conducted a small exploratory study as a follow-up, recruiting four new participants. We asked participants to complete similar tasks to those of study 1, with a subset of the visual variables (color, motion, and shape). We doubled the presentation time from 240ms to 480ms.

6.1 Participants and Recruitment

Four participants were recruited from the local university community through the University of Saskatchewan's online bulletin board and were given an honorarium of $10. All participants were students, reported normal or corrected-to-normal vision, and had no diagnosis or history of color-vision deficiencies. All participants were experienced with mouse-and-windows desktop application (10 hrs/wk).

6.2 Apparatus

The study used a similar setup to that described for Study 1 in Chapter 4.2, with three Asus 27-inch UHD LCD panels (Figure 6.1) 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 Windows10 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.
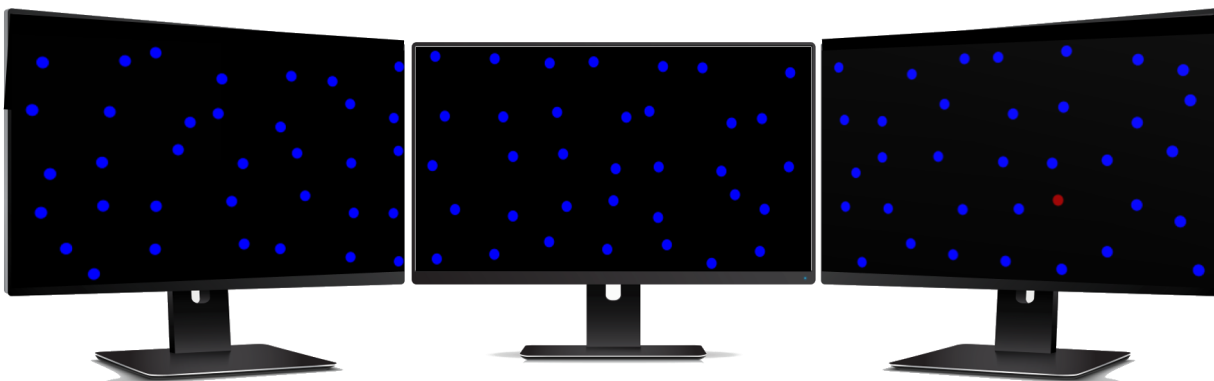
Figure 6.1: Visual field for a trial

6.3 Tasks

All three base visual variables: color, motion, and shape were presented at five intensity levels. 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 trials with each intensity level began, the study system showed how each target and the distractors would look for that level. The target maintained the same appearance for all 48 trials of the level. Across all levels and blocks, each visual variable was presented in 480 trials (48 trials x 5 levels x 2 blocks); 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 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 480ms (Figure 6.1). 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 [42].
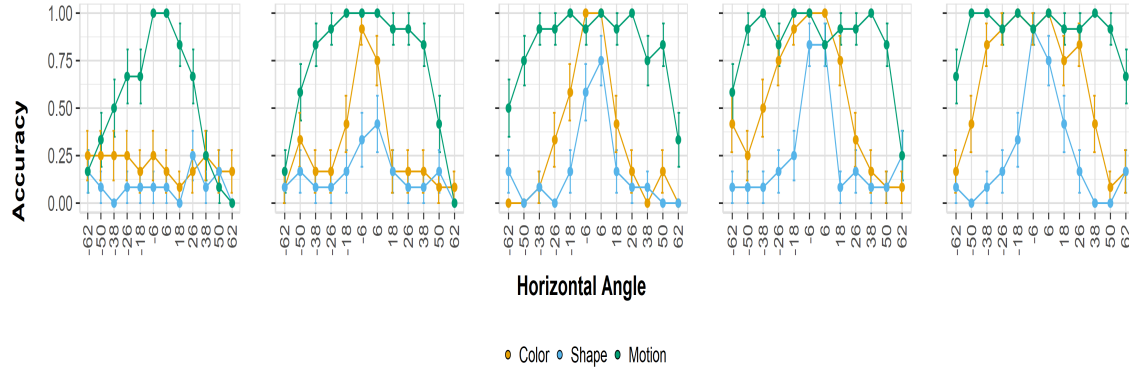
Figure 6.2: Increased Presentation Time (480ms).

6.4 Study Design and Analysis

Similar to study 1 presented in Chapter 4, the follow-up study used a repeated-measures within-participants design, with accuracy (percentage of correct responses) on trials with a target present as our dependent measure, and three factors:

- *Visual Angle*: The horizontal angle of the target from the fixation cross ($\pm6°$, $\pm18°$, $\pm26°$ $\pm38°$, $\pm50°$, and $\pm62°$).

- *Variable*: The visual variables used to create a popout effect (color, motion, and shape).

- *Intensity Level*: The discriminability between our target visual variable and the distractors (Figure 3.5). The study used five levels of intensity for our visual variables.

6.5 Results

Results from the follow-up study are summarized in Figure 6.2. Averaged across all angles and levels, perception accuracy at 480ms presentation time was 75% for motion, 39% for color, and 18% for shape. Similar to study 1 in Chapter 4, perception accuracy decreased as visual angle increased. Perception accuracy for Study 1 with 240ms presentation time for the three variables was 76%, 34%, 18%, respectively. Results from both studies are summarized in Figure 6.3.

Our study is highly exploratory, with only four participants. However, our limited results suggest a non-linear relation between presentation time and noticeability; determining the effects of stimuli presentation times and noticeability requires further exploration.
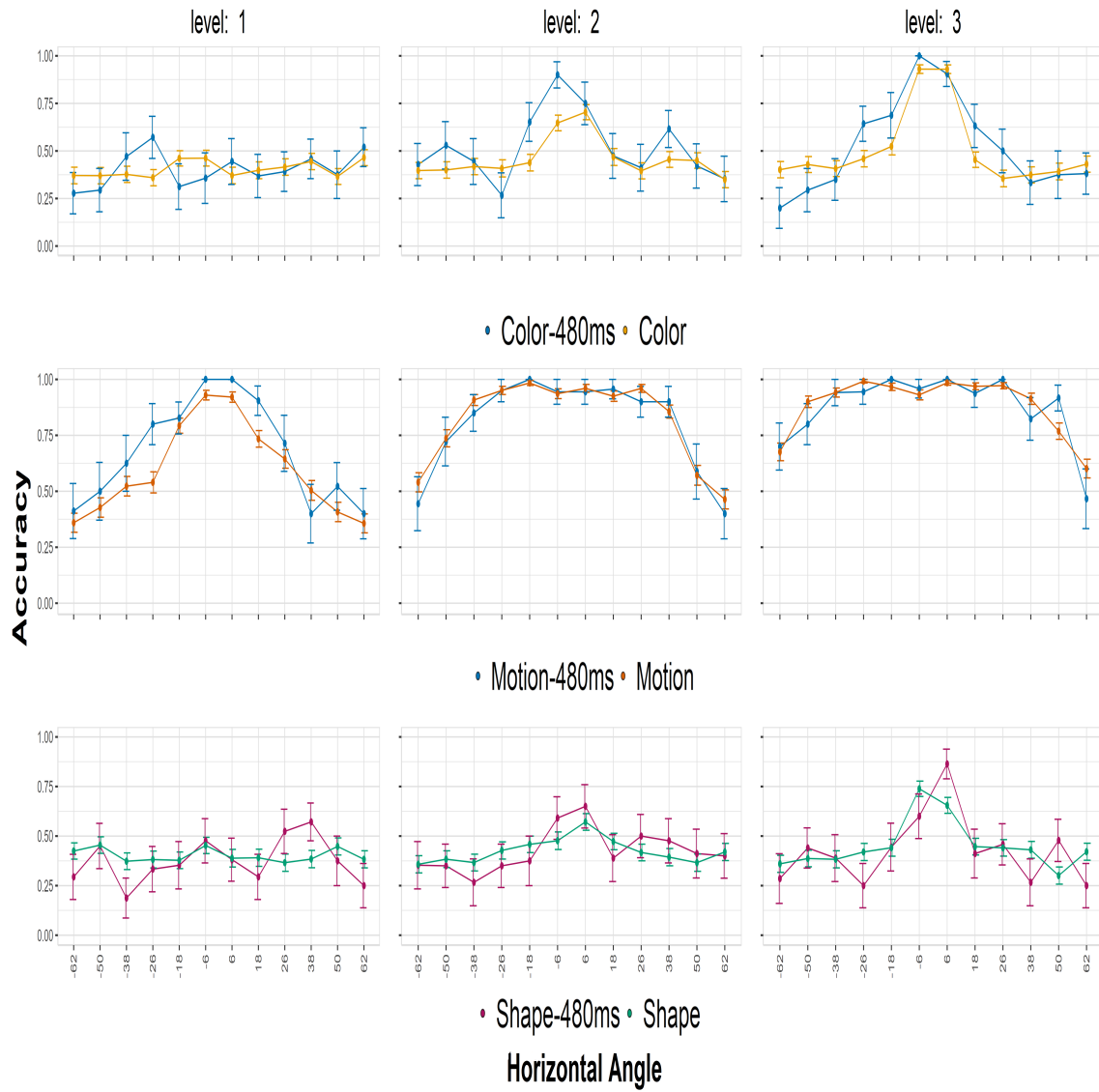
Figure 6.3: Comparison of results. Follow-up study results (Color 480ms, Motion 480ms, Shape 480ms) and Study 1 results with 240ms (Color, Motion, Shape).

CHAPTER 7

DISCUSSION

In Chapter 1 we identified the need to examine how users perceive different visual effects to guide the design of peripheral notifications. In this chapter, the results from our user studies are analyzed and discussed to determine what scientific contribution has been gained in the context this primary research objective. To do so, the results of the research will first be reviewed, and then the principal problem posed in Chapter 1 will be considered using these results. We will explore the limitations in this work, discuss how the above research can be generalized to other domains, and outline potential directions for future work.

7.1 Summary of Results

Our two quantitative user studies provide several findings:

- **Noticeability of Combinations of Visual Features:** In Chapter 4, a study was performed to evaluate the noticeability of three visual variables and their combinations at different angles and intensities. While the noticieability of our different visual varied by angle and intensity level, the overall noticeability of visual features decreased as visual angle increased. Perception accuracy ranged from 83% at $\pm6°$ from the center to less than 20% at $\pm62°$. Furthermore, combining visual features does not improve instantaneous noticeability in the periphery. Accuracy with the pair-wise combinations of the visual variables mirrored the performance of the strongest variable by itself.

- **Noticeability of Visual Features when Users Attend a Primary Task:** In Chapter 5, a study was performed to evaluate the noticeability of a subset of the visual variables from study 1 at different angles and intensities while users attended to a primary task. The primary task was a custom version of the classic game Snake [1]. The visual variables in study 2 were dynamically placed at different angles based on the user's view direction. Similar to study 1,

noticeability of visual features decreased as visual angle increased; however, performance of the visual variables differed to that of study 1. Accuracy decreased in detecting the *motion* visual variable in study 2, and detection of *color* increased, when compared to results of the first study. This result suggests that there are variations in how the noticeability of different visual variables change depending on the visual characteristics of the primary task.

- **Distracting Visual Features:** Additionally, the study in chapter 5 used a *score* variable to keep track of user performance during presentation of the different visual variables, which served as a rough measure of distraction (the cognitive load from attending to the visual variables acting as visual notifications). The results from this study found that on average, game score during the presentation of the motion visual variable was lower across all intensity levels. This result suggests that the cognitive load for attending to different visual variables differs depending on the visual variable.

Our user studies also provide the two following secondary findings:

- **Detection Bias Towards Left Side of Visual Field:** The studies presented in Chapters 4 and 5 presented the visual variables across the human visual field (up to 62° for both left and right sides). Results from analyzing performance for each side of the visual field found that participants showed a bias towards the left side of the visual space, resulting in an increased accuracy of detecting the visual variables presented on the left side of the visual field.

- **Non-linear Relation Between Noticeability and Presentation Time:** We doubled stimuli presentation time from 240ms used in Study 1 to 480ms in our follow-up study presented in Chapter 6. Mean accuracy results across all angles and levels for this follow-up study are approximately equal to those of Study 1. While our results are highly exploratory, they suggest a non-linear relation between presentation time and noticeability.

7.2   Explanation of Results

7.2.1   Independence of Pathways

Our finding that feature combinations do not offer an improvement in noticeability may be explained through prior findings that saliency detection mechanisms are not completely independent (e.g., [74]), as reviewed in Chapter 2.3. However, to the best of our knowledge, the 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 generalise to peripheral stimuli due to the different visual mechanisms used in these regions [59, 110]. Features such as color and motion are processed using different pathways and cells in the brain, and the density of these cells vary across regions of the human visual field.

As participants focused on the Snake game in our second study, accuracy with *Motion* dropped in comparison to Study 1's findings, which contrasts with the findings for *Color*, which was more accurate in Study 2 than Study 1. 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 [51, 31]. However, a clear explanation to the process driving motion results is still lacking [85]. In general, it seems likely that the snake's motion diminished 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 [19, 25, 100], including attentional resolution [46], motion processing and contrast sensitivity [23].

7.2.2   Experimental Factors

We designed the different intensity levels in our studies to provide similar increments in discriminability between the distractors and our target. One important issue, however, must be taken into account - there exist different ranges of intensity that can be applied to our visual variables. While the range for color is limited by the distance the distractor and the target, other variables such as motion have a much larger possible range. It is possible our results were affected by the different intensity level manipulations we used. This is because there does not exist a direct way to equate the perceptual differences in intensity levels for the visual variables (i.e., the difference in red for color at level 3 may not equate to the difference in motion at level 3).

7.2.3   Differences Between Study Tasks

While we designed the interfaces from both studies to resemble each other as much as possible, there are notable differences between the main tasks of both studies. Study 1 required users to stare at a fixation cross in the center of the screen, which was followed by the presentation of the main trial (an object field with distractors and a possible target), after which participants responded to

whether they had seen the visual target. Study 2 had users play a game, during which the visual target flashed at different time intervals, and required users to press a key whenever they detected the visual target. While the visual variables, angles, and intensity levels remained constant across both studies, it is difficult to equalize the perceptibility of different visual variables when used in vastly different tasks, so to some degree, our results must be treated as independent.

7.3 Implications of Results

The implications of the results from the studies in this thesis are now explored. This is done by examining the original problem presented in Chapter 1 and exploring how these results address this problem.

The original problem stated as a motivator for this thesis was:

> There is little known about how visual features of notifications, and their combinations, affect noticeability and distraction across the visual field.

As a solution to this problem, this thesis aimed to study how users perceive different visual effects (color, shape, and motion), and their combinations at varying angles and intensity levels, presented both in isolation and when users attend to a primary task. Ultimately, an overall summary of our studies is: first, different visual variables responded differently to increasing angle and intensity level, and, increasing visual angle led to an overall performance drop. Second, combinations of visual variables did not improve instantaneous noticeabiltity; third, noticeability of different visual variables in the periphery change depending on the visual characteristics of the primary task; fourth, different visual variables lead to different effects on primary task performance.

7.3.1 Design Implications for Peripheral Notifications

Our findings are applicable in a number of different contexts. There are several lessons that designers of peripheral notifications (and notifications in general) can take from our work. This study clearly indicates that there are differences in noticeability for notifications depending on the visual effect used. 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 visual stimuli examined is 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. For example, users are able to perceive motion effects with high accuracy even at wide angles and low intensity levels levels. At level 1, our tested motion effects involved movements of only a few pixels on the screen (1mm of movement), yet results suggest a better accuracy than higher levels with other visual variables or their combinations. Bertin suggests that variations in individual visual variables are effective for encoding information and achieving noticeability [16]. 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, suggesting that motion is more distracting than other visual effects and requiring a greater cognitive load to attend to than other visual 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 [66]. Some situations require notifications that do not disrupt a primary task, and in these context motion is likely a poor choice for notification unless the notification's purpose is urgent. A possible solution for using motion is adjusting motion displacement depending on the display size, or gaze tracking, which will achieve similar noticeability, with smaller distraction effects. For situations that explicitly require notifications to prompt task-switching and immediate noticeability, motion cues are likely to be the most effective and powerful effect.

The studies presented in this thesis attempted to measure the noticeability of different visual effects by using performance-based noticeability metrics; in both studies noticeabilty was measured using user's accuracy in detecting the visual effects among distractors when flashed for 240ms. As we show the performance of different visual variables based on instantaneous noticeabilty, our results can be applicable in a number of contexts, particularly when designing notifications. First, previous work has shown that alerts are often difficult to see in multi-display environments [37], which is a substantial problem for control rooms, systems for emergency response, and aircraft cockpits. Designers can use the findings from our studies to help inform the design of notifications for multiple display environments and peripheral displays based on empirical evidence.

Second, our studies provide a better understanding of the cognitive load demands of the different visual variables. The results from the studies show that performance-based measures of noticability and distraction (e.g., detection accuracy and task performance) can be used to identify differences

between different visual variables at different intensity levels. These results mean that designers can use methods presented in this thesis to evaluate how noticeable and distracting different visual effects when designing notifications for user interfaces.

Third, the visual effects we evaluated can be easily reproduced in many state-of-the-art UI toolkits and content creation packages for desktop and web interfaces (such as Java, HTML/CSS, Blender, Maya). The parameters we used can be useful in helping designers/researchers identify and evaluate classes of visual effects not yet explored. The ease of replicating the different visual effects in many UI toolkits opens up the possibilities to extending the use of our results beyond just notifications and into the design for other UI elements such as widgets, buttons, or windows.

7.4   Limitations and Future Work

In this thesis, we evaluated the noticeability and distraction effects of different visual variables with to better understand how users interpret and perceive notifications in large-screen environments. To provide these insights, we used a variety of visual effects to identify exactly how accurate users are at detecting these effects and their cognitive load when attending to them. We tested participants in a laboratory setting, first having them detect our visual cues among distractors. We then evaluated the change in when users played a game as their primary task. The nature of laboratory testing, our tasks and participant pool has its limitations, and our findings prompt us to consider ideas for future work.

A first limitation of our studies is that the variables we tested were not actual notifications. The visual variables we used were approximations to the visual effects used in modern user interface notification systems. Our visual variables did not carry any important message for the users. There is a need to explore these visual variables in a more realistic setting - we intend to investigate these visual effects used as actual notifications in future work to improve our understanding of how noticeable and distracting peripheral notifications can be.

Laboratory testing limited our participant pool to participants from our local university pool, preventing us to test a wider range of participants. Additionally, the task (snake game) used for study 2, and the score variable used to track user performance and inform us the distraction caused by the presentation of the visual variables, may have not been of any particular importance to our users, and as such, they may have had an easier time detecting visual variables as an intense focus on the primary task is not perceived as critical. Users of some systems that can employ peripheral

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notifications (such as control rooms for emergency response) are often under an immense amount of pressure, and maintain great focus on their tasks - which could potentially reduce the accuracy in detecting visual variables.

This research has studied the additive effects of popout cues across the visual field, and explored their effectiveness and distraction in an applied setting. There are, however, many opportunities for extending these 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.

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 [16], 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.

On top of these core limitations and future work, there are additional research directions to explore:

- **Investigate different kinds of primary tasks:** The task in Study 2 presented in Chapter 5 was dominated by motion effects. Our findings from the study suggest that motion effects in notifications are less likely to be noticed when the primary task is also dominated by motion. There is limited information on whether a primary task dominated by other visual effects would decrease the noticeability of notifications with the same visual effect (e.g., a color intensive primary task, and a color-based notification), or a combination of these effects (a notification comprised of two visual effects, and a task dominated by a single effect).

- **Noticeability of notifications in larger displays (e.g., wall displays):** We tested our visual variables in a triple-monitor setting, a common setup in many modern work-spaces. However, larger displays are also common. Many of these, such as the Microsoft Surface

Hub[1] offer displays with a screen size up to 84in, and are used in offices with the intention to increase productivity and collaboration. In these larger displays, most of the screen will be in the user's periphery, and we need to investigate how noticeable notifications are when screen displays size expands from that available from common desktop displays.

- **Extend popout visual features to visual search:** Many tasks in user interfaces require users to search for an item on the screen (such as an icon used to open an application). We intend to investigate which visual effects are best at reducing visual search time and improving accuracy (e.g., "count all of the targets" where targets have a combination of visual features).

- **Investigate fatigue caused by visual effects:** In the studies presented in this thesis we did not analyze performance changes in detecting the peripheral cues as the study progressed. As laboratory studies have the potential of lasting one hour or more, we intend to investigate whether there are any fatigue effects caused by our studies, in particular, investigate whether the presentation of a specific visual effect can increase user's fatigue.

- **Investigate notification performance given primary task attachment/level of focus and motivation:** Our main task for the game presented in Study 2 involved a growing snake, where the participants helped the snake grow as they completed the game objective (eating the green apples). This means that as participants progressed among the different experimental tasks (detecting notifications), their snake could potentially grow very large and achieve a high score in the game. We intend to explore whether task performance and focus has any effect in detecting peripheral notifications (i.e., as the snake's length grows larger, are participants more focused on detecting the peripheral cues or keeping the snake alive and growing?).

- **Evaluate distraction caused by increased presentation time of notifications:** We intend to examine the relationship between visual presentation time and noticeability, adding measures of distraction to primary tasks. While our follow-up suggests that doubling presentation time did not increase noticeability as expected, an increased presentation time of a peripheral notification may have more notable effects of distraction.

- **Investigate issues of notifications in VR:** In a virtual 3D environment notifications can not always be placed directly in front or near the user's view, as the notification is likely to affect overall readability of the 3D rendering of the scene. Furthermore, due to the immersive

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[1]https://www.microsoft.com/en-us/surface/business/surface-hub

nature of VR environments, a sudden notification may startle a user. As the user controls the point of view in a VR environment, notifications must be designed such that a user is convinced that there is an important message in the virtual environment that needs their attention. A potential area of work is to investigate whether these visual effects can be rendered in 3D such that they are effective drawing a user's attention in VR.

Chapter 8

Conclusion

Notification systems are integral to interactive desktop environments. Visual notifications play an important role in interactive computing systems by providing rapid availability to information in an effective manner. While notifications may vary in importance to users, notifications are valuable for users as a way of keeping aware of information while attending to a primary task. While visual notifications have been around for a long time on standard desktop environments, new computing environments with larger screens add new factors that have to be taken into account, as most of the system will be in a user's periphery, where it is harder to notice visual effects. A variety of visual effects can potentially be used to design and create noticeable and engaging notifications; however, a balance must be struck between various design goals.

Designers are required to address a trade-off between desired noticeability and unintended distraction. Combining visual features (e.g., color and motion) is a common design approach for improving noticeability; however, little is known about how accuracy in detecting visual features across the visual field changes when visual features are combined. In order to adress this question, we designed and implemented a system to test how well participants can detect visual variables and their combinations up to 60° of the visual field. Results from these studies suggest that strong, stand-alone, popout cues are as effective in achieving noticeability as popout feature combinations.

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 certain stimuli, such as motion, have adverse effects to 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. We introduced a design framework for peripheral

notifications and we outlined possible opportunities for future work including investigating how noticeable notifications are when screen displays size expands (such as the ones available in wall displays) from that available from common desktop displays, extending popout visual features to visual search, and investigating how an increased presentation time of notifications affect primary task performance.

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Appendix A

Study Consent Forms

UNIVERSITY OF SASKATCHEWAN

> **Department of Computer Science**
> 176 Thorvaldson Building
> 110 Science Place   Saskatoon SK S7N 5C9   Canada
> Telephone: (306) 966-4886   Facsimile: (306) 966-4884

Participant Consent Form

You are invited to participate in a research study entitled: *The effects of visual angle, stimuli intensity, and combinations of stimuli on peripheral pop-out effects.*

This consent form, a copy of which has been given to you, is only part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. If you would like more detail about something mentioned here, or information not included here, please ask. Please take the time to read this form carefully and to understand any accompanying information.

Researcher(s):

Dr. Carl Gutwin
Professor, Undergraduate Chair
Department of Computer Science
University of Saskatchewan
(306) 966 - 8646
gutwin@cs.usask.ca

Aristides Mairena
Graduate Student
Department of Computer Science
University of Saskatchewan
(306) 261 - 6705
aristides.mairena@usask.ca

Purpose and Objective of the Research:

- Determine the effects of visual angle, stimuli intensity, and combinations of stimuli on people's ability to perceive different types of pop out effects across multiple monitor work spaces.

- The goal of the research is to improve design of alerts in multi-display environments, by better understanding the capabilities of users' peripheral vision.

Procedures:

- The session will require **120** minutes, during which you will be asked to complete a task involving the use of peripheral vision to identify unique targets out of a set of visual stimuli.

- You will be asked to fill out a demographic questionnaire before beginning the study. As well as asked to evaluate your performance after each round of the study, and indicate the difficulty of the task.

- This study will take place in the Human-Computer Interaction Lab at the University of Saskatchewan.

- Please feel free to ask any questions regarding the procedures and goals of the study or your role.

- At the end of the session, you will be given more information about the purpose and goals of the study, and there will be time for you to ask questions about the research.

Page 1 of 3

Funded by:

- The University of Saskatchewan.

- The Natural Sciences and Engineering Research Council of Canada (NSERC).

Potential Risks:

- Your hands/fingers/eyes may get tired using our computer software system.
- This will be addressed by allowing you to rest between every round as long as you like.

Compensation:

- As a way of thanking you for your participation and to help compensate you for your time and any travel costs you may have incurred, you will receive a **$20** honorarium at the end of the session.

Confidentiality:

- All personal and identifying data will be kept confidential. A participant ID number will be used, and no link will be kept between your participant ID and any identifying information about you.

- The anonymized data collected from this study will be used in articles for publication in journals and conference proceedings.

- **Storage of Data:**
    - o This informed consent form and all research data will be kept in a secure location under confidentiality, in accordance with University policy, for 5 years after publication.

Right to Withdraw:

- Your participation is voluntary and you can answer only those questions that you are comfortable with.

- **You are free to withdraw from the study at any time without penalty and without losing any advertised benefits.**

- Withdrawal from the study will not affect your academic status or your access to services at the university.

- If you withdraw, your data will be deleted from the study and destroyed.

- Your right to withdraw data from the study will apply until data has been pooled. After this, it is possible that some form of research dissemination will have already occurred and it may not be possible to withdraw your data.

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Follow up:

- As one way of thanking you for your time, we will be pleased to make available to you a summary of the results of this study once they have been compiled (usually within six months). This summary will outline the research and discuss our findings and recommendations. This summary will be available on the HCI lab's website: http://www.hci.usask.ca/

Questions or Concerns:

- Your continued participation should be as informed as your initial consent, so you should feel free to ask for clarification or new information throughout your participation. If you have further questions concerning matters related to this research, please contact:

    o Dr. Carl Gutwin, Professor, Dept. of Computer Science, (306) 966-8646, gutwin@cs.usask.ca

- This research project has been approved on ethical grounds by the University of Saskatchewan Research Ethics Board. Any questions regarding your rights as a participant may be addressed to that committee through the Research Ethics Office ethics.office@usask.ca (306) 966-2975. Out of town participants may call toll free (888) 966-2975.

Consent:

Your signature below indicates that you have read and understand the description provided:

I have had an opportunity to ask questions and my/our questions have been answered. I consent to participate in the research project. A copy of this Consent Form has been given to me for my records.

Name of Participant	*Signature*	*Date*

Name of Researcher	*Researcher's Signature*	*Date*

A copy of this consent will be left with you, and a copy will be taken by the researcher.

Page 3 of 3

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Participant Consent Form

You are invited to participate in a research study entitled: *Investigating Noticeability and distraction of Visual Features of Peripheral Notifications*

This consent form, a copy of which has been given to you, is only part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. If you would like more detail about something mentioned here, or information not included here, please ask. Please take the time to read this form carefully and to understand any accompanying information.

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Aristides Mairena
Graduate Student
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University of Saskatchewan
(306) 261 - 6705
aristides.mairena@usask.ca

Purpose and Objective of the Research:

- Determine the effects of visual angle, stimuli intensity, and combinations of stimuli on people's ability to perceive different types of pop out effects across multiple monitor work spaces when users focus in a primary task.

- The goal of the research is to improve design of alerts in multi-display environments, by better understanding the capabilities of users' peripheral vision and its interaction with a primary task.

Procedures:

- The session will require **60** minutes, during which you will be asked to complete a task involving the use of peripheral vision to identify unique targets out of a set of visual stimuli.

- You will be asked to fill out a demographic questionnaire before beginning the study. As well as asked to evaluate your performance after each round of the study, and indicate the difficulty of the task.

- This study will take place in the Human-Computer Interaction Lab at the University of Saskatchewan.

- Please feel free to ask any questions regarding the procedures and goals of the study or your role.

- At the end of the session, you will be given more information about the purpose and goals of the study, and there will be time for you to ask questions about the research.

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- Your hands/fingers/eyes may get tired using our computer software system.
- This will be addressed by allowing you to rest between every round as long as you like.

Compensation:

- As a way of thanking you for your participation and to help compensate you for your time and any travel costs you may have incurred, you will receive a **$10** honorarium at the end of the session.

Confidentiality:

- All personal and identifying data will be kept confidential. A participant ID number will be used, and no link will be kept between your participant ID and any identifying information about you.
- The anonymized data collected from this study will be used in articles for publication in journals and conference proceedings.
- **Storage of Data:**
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  o Dr. Carl Gutwin, Professor, Dept. of Computer Science, (306) 966-8646, gutwin@cs.usask.ca

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Name of Participant	_Signature_	_Date_

Name of Researcher	_Researcher's Signature_	_Date_

A copy of this consent will be left with you, and a copy will be taken by the researcher.

APPENDIX B

STUDY QUESTIONNAIRES

Participant Demographics

1. Participant ID

[   ]

2. Sex

☐ Male
☐ Female

3. Age

[   ]

4. Are you a student?

○ Yes
○ No

5. If yes, what is your field of study?

[   ]

6. On average, how many hours do you spend on desktop/laptop computers per day?

[   ]

7. Do you work with multiple display setups? If so, how many displays?

[   ]

8. Do you have colour blindness deficiency?

○ Yes
○ No

9. Do you have known peripheral vision deficiency?

○ Yes
○ No

Popout Study Effort Questionnaire

1. Participant ID

[   ]

2. Condition ID

[   ]

3. How mentally demanding was the task?

1 (low) 7 (high)

4. How physically demanding was the task?

1 (low) 7 (high)

5. How hurried or rushed was the pace of the task?

1 (low) 7 (high)

6. How successful were you in accomplishing what you were asked to do?

1 (low) 7 (high)

7. How hard did you have to work to accomplish your level of performance?

1 (low) 7 (high)

8. How insecure, discouraged, irritated, stressed, and annoyed were you?

1 (low) 7 (high)

Study 2 Effort Questionnaire

All of these questions are concerned with noticing the visual variable while playing the snake game.

1. Participant ID

[   ]

* 2. Condition ID

[   ]

* 3. How mentally demanding was the task?

1 (low) 7 (high)

* 4. How physically demanding was the task?

1 (low) 7 (high)

* 5. How hurried or rushed was the pace of the task?

1 (low) 7 (high)

* 6. How successful were you in accomplishing what you were asked to do?

1 (low) 7 (high)

* 7. How hard did you have to work to accomplish your level of performance?

1 (low) 7 (high)

* 8. How insecure, discouraged, irritated, stressed, and annoyed were you?

1 (low) 7 (high)

* 9. How distracting was the visual variable?

1 (low) 7 (high)

* 10. Did the visual variable cause you to 'die' in game?

○ Yes
○ No

Study 2 Exit Questionnaire

1. Which visual variable was easier to notice?

○ red circle
○ moving circle

Question Title

* 2. Which visual variable was more distracting?

○ red circle
○ moving circle

Question Title

* 3. Following up to the previous question, why do you feel that way?