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Evaluation of detection and discrimination ability of peripheral vision on notification information based on large displays

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ABSTRACT

Large displays enable users to perform several tasks simultaneously. Under such circumstances, notification information provided through the concept of ambient displays plays a vital role in assisting users to switch among tasks. This paper presents the experimental results of a notification system design in the peripheral region of large displays. The aim is to provide guidance for notification information design by investigating detection and discrimination performance of human observers when visual notification information is presented away from the foveal region and viewed using peripheral vision. The proposed notification system was designed using an array of glyphs. Each glyph is a small gray square with a fixed size of 60 × 60 pixels. By changing the gray levels of adjacent glyphs dynamically, a glyph array presents a particular dynamic pattern. The experiments involved testing factors that comprised the visual angle, size and shape of glyph arrays, frequency of temporal modulation, phase shift of each pattern, and number of stimuli. The results show that glyph arrays are detected accurately if they are larger, even at wide viewing angles, and that the number of glyphs in a glyph array affects the performance more than the shapes of glyph arrays do. Furthermore, the discrimination performance is higher when both the frequency and phase are manipulated simultaneously (multidimensional design), compared with the case when each of these dimensions is varied separately (single-dimensional design). When the number of stimuli is set at 8, for example, users can maintain an accuracy rate of 70% for the multidimensional design, whereas the accuracy rate is only approximately 60% for the single-dimensional design.

1. Introduction

Large high-resolution displays are leading the growth in the global display market. NPD Display Search indicated that in January 2005, the average desktop monitor size for personal workstations was 16.4″ and by 2013, the corresponding average measurement was 20.9″. For the professional graphics market, the largest market share by size in 2013 was 27″ displays, and curved displays with a size of up to 40″ are currently available. A larger display provides more space to present information, thereby supporting various tasks for users simultaneously and in a more detailed view than on a smartphone or tablet [1].

In addition to the trend of increased display size, many people currently enjoy maintaining awareness of information such as news, the weather, entertainment, and other personally relevant information when interacting with a computer [2,3] or a smart device [4,5]. Such information is typically provided by a notification system that transmits current and timely information efficiently and effectively without causing unwanted distraction to a user's ongoing tasks [6]. A notification system can be used for several purposes including (1) receiving news [7], (2) interacting with social groups [8,9], and (3) delivering information through notifications such as time-sensitive data [10]. According to the priority of the information being conveyed, the display of notification systems can be divided into two categories: ambient and alert. An ambient display shows low-priority information and requires divided human attention, whereas an alert display shows prioritized information demanding focused attention [10].

Notification information can be transmitted differently through human modalities such as visual, auditory, tactile, olfactory, and multimodal [11–14]. Arroyo et al. [15] compared five notification modalities—heat, smell, sound, vibration, and light—from the aspect of disruption. The results indicated no considerable differences among the five transmission methods regarding disruption. Warnock et al. [14] compared eight delivery methods categorized into four groups: visual, auditory, tactile, and olfactory. The visual group comprised text, pictograms, and abstract visual stimuli; the auditory group comprised voice, earcons, and auditory icons; the tactile group comprised tactons; and the olfactory group

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comprised aromacons regarding disruptiveness and effectiveness. The results indicated that the users demonstrated considerably higher accurate responses to the notification via visual and audio transmissions than they did via tactile and olfactory transmissions. Regarding the response time, the users had the shortest response time to the visual cues and the longest response time to the olfactory cue. From the aspect of disruption, tactile and olfactory transmissions introduced more disruption to the users than visual and auditory cues did.

These studies have suggested that, compared with other human modalities, visual and auditory cues provide optimal transmission to users regarding disruption, response time, and accuracy. However, auditory cues are designed to prompt immediate action, whereas visual cues are not designed for vigilant types of tasks [16]. This suggests that auditory cues are more suitable for alert displays and visual cues are more suitable for ambient displays.

1.1. Visual cue

Because this study focused on nonemergent information types, the information transmission was designed on the basis of visual cues. Different forms of visual cues, such as text, patterns, pictograms, shapes, and colors, can be used for transmitting information. The transmission method can be either static or dynamic and the presentation of the transmitted information can be abstract or concrete.

Numerous peripheral awareness systems have been created to support abstract presentation [17–20]. Tarasewich et al. [11] combined color and position on three LEDs and conveyed 27 messages with high recognition accuracy for users. One of the peripheral awareness systems, ambient media, comprised physical devices, such as money color [21], breakaway [22], and daylight displays [23], that were placed in a person's environment. Hung and Ostovari [24] designed an assistive interface in which hints (e.g., changing the color of a cursor) are provided to attract a user's attention to a notification that is initially displayed in the peripheral region outside the user's field of view.

An example of concrete presentation involves text information. Plaue and Stasko [2] compared different peripheral display configurations for text information. McCrickard et al. [25] compared three animation notification systems (i.e., blast, fade, and ticker) with no animation regarding the correct rate, hit rate, and false alarm rate. The results showed that the blast and fade animations resulted in considerably faster monitoring times than the ticker did. The hit rate for the ticker was higher than that for the fade and blast.

1.2. Design for human peripheral vision

When interacting with large displays, users generally separate the focal region from the peripheral region depending on the priorities of tasks, and they can take advantage of peripheral vision to monitor applications of lower relevance by placing them in the peripheral areas of the display [26]. Therefore, demand is increasing for using peripheral displays in maintaining awareness [3,7,27], in which users tend to glance at or use peripheral vision to view low-priority information.

Anderson et al. [28] measured spatial contrast sensitivity functions at retinal locations from 0° to 55° along the nasotemporal meridian for a single eye and found that contrast sensitivity functions for peripheral vision are shaped similarly to those observed foveally, but are shifted to lower spatial frequencies. In particular, there is a clear nasotemporal asymmetry in contrast sensitivity in the far peripheral visual field. Stimuli imaged on the nasal retina are detected with higher sensitivity than those imaged on the temporal retina.

Legge et al. [29] linked the spatial and temporal properties of letter recognition to reading speed for text viewed using central or peripheral vision. They found that the size of the visual span decreased from at least 10 letters in central vision to 1.7 letters at 15° eccentricity, concluding that the retinal position, exposure time, and relative position within a character string are key factors that limit letter-recognition accuracy. Chung et al. [30] compared the effects of central and peripheral vision on the spatial-frequency characteristics of letter identification, determining that the spatial frequency tuning and scaling properties for letter identification were similar between the fovea and periphery.

In addition to letter-like stimuli, human peripheral vision in texture segregation and contour integration also has crucial implications in pattern and object recognition. Joffe and Scialfa [31] investigated texture segmentation as a function of eccentricity and concluded that optimal texture segregation does not peak in foveal vision but does so in the near periphery. Experimental evidence suggests that contour integration is mainly present in foveal vision [32,33]. However, recently Kuai and Yu [34] demonstrated that for contour stimuli such as circles and ellipses, which bear favorable Gestalt properties, contour integration for shape detection and discrimination was nearly constant from the fovea to up to 35° of visual periphery.

The cones and rods in the human retina provide different ocular capabilities. The cones are efficient for visual acuity, visual resolution, and color recognition, and the rods are effective for motion detection. The cell density is a function of the retinal angle; where away from fovea, the retina is composed primarily of rod receptors with extremely few cones [35]. Although this may imply that human peripheral vision is sensitive to motion and is relatively ineffective for color discrimination, it is now well known that peripheral color vision is similar to foveal vision if the target is sufficiently large. Gordon and Abramov [36] measured the spectral hue and saturation functions of the nasal retina both at and 45° from the fovea. Using large and small targets in the fovea (1.5° and 5′) and periphery (6.5° and 1.5°), they found that the quality of color vision in the periphery depends crucially on stimulus size. A sufficiently large stimulus enables detecting a complete range of well-saturated hues.

1.2.1. Dynamic design for peripheral vision

Notification information is widely presented using animation [2,25] because dynamic presentations obviously attract more attention than static presentations do; the efficiency of such presentations is generally evaluated according to glanceability [37] instead of studying peripheral vision directly. Research on the perception and recognition ability of peripheral vision has largely focused on static information (e.g., a fixed color or word); only a few studies have focused on the effects of dynamic information. Bartram et al. [38] reported that motion cues draw more attention than do static representations, and some motion types (e.g., traveling motions) are more distracting and irritating than other types (e.g., anchored motions). They suggested that traveling motion requires more attention because in addition to detection, a cognitive act of tracking is involved. Park and Nam [39] used card sorting skills to extract four dynamic design elements: tempo, direction, rhythm, and volume. They suggested that in the case of presenting information, complex information tends to require more design elements or coding dimensions compared with simple information. Yamada et al. [40] developed an information notification method called peripheral cognition technology. They applied the phenomenon of visual field narrowing (VFN), in which the human visual field narrows considerably during a difficult task, to design a peripheral agent. When a new message arrives, this agent appears in a peripheral visual area outside the visual scope of the primary task. Because of VFN, users may not notice the onset of this agent