Abstract. This paper is about visualization of information through peripheral vision i.e. how to exploit peripheral vision displays. The purpose of this study is to investigate how peripheral vision can be used for releasing resources from central vision. An overview of paradigms and opportunities in human vision is made for a better understanding regarding; benefits and objections for using peripheral vision displays. Guidelines for design of information visualization through peripheral vision are presented. The hypothesis is that these design principles differ from information visualization through central vision. In conclusion information presented in the periphery is more sensitive for bad design choices than information presented in central vision.

1 Introduction

Today foveal vision is currently used in most systems while peripheral vision is an unused resource. With a peripheral vision display users can interpret and take notice of presented information without a straight look at the display. When designing a peripheral vision display it is important to understand how the system should be developed according to the available resources for information retrieval. An introduction over abilities and limitation of the foveal vision and peripheral vision has been presented for an overall picture of human perception. This is followed by how peripheral vision can be used for information retrieval.

There are four terms that first should be distinguished from each other; peripheral information, peripheral information displays, peripheral vision information and peripheral vision displays.

Peripheral information is a term for secondary information and is often used in the connection of a secondary task. The name refers to that the information is in the periphery of a user, not in the peripheral vision field of a user. The characteristics of peripheral information makes it suited for presentation in the peripheral vision field. A simple example of peripheral information is the time of day.

Peripheral information displays, PID, or peripheral displays, presents the peripheral information. Neither the display nor the presentation technique
is specified and information on peripheral information displays is often presented in such a way that it must be accessed through foveal vision. It is not required that recognition and identification must be possible through peripheral vision. A popup-window informing the user that a new email was received is one example of a peripheral information display.

**Peripheral vision information** is information that can be interpreted using peripheral vision.

**Peripheral vision displays**, PVD, present information in such a way that it can be interpreted through peripheral vision. These displays serve to release attention for a primary task though secondary information from other sources often must be interpreted in parallel. Three examples of peripheral vision displays are described in the introduction of peripheral vision displays.

The term peripheral information displays is currently used in different contexts and can therefore easily cause confusion if peripheral vision is used or not [1]. For specifying that information is interpreted through peripheral vision, the term **peripheral vision displays** is preferable to use.

## 2 Human Vision

The visual field has the capacity to cover an angle that is approximately 150 degrees horizontal and 130 degrees vertical [2]. Head movement is often used in combination if the focus shift is greater than 15 degrees [3]. Figure 1 shows properties of the visual field and defines terms that are used in this article. **Foveal vision** extends one degree from the gaze point[4], has high acuity and is the main source for visual information to the brain [5] Foveal vision also plays a decisive role in colour perception. The colour sensitive cones are distributed with a high density in the foveal vision field. **Parafoveal vision** is the area surrounding the fovea out to a visual angle of five degrees [4] and with a wider angle we have the peripheral vision field. Parafoveal vision contains a mixed distribution of cones and light sensitive rods that result in a resolution not as high as the foveal vision [6]. The term **central vision** is used, in this article, to refer both foveal vision and parafoveal vision. The main purpose of central vision is recognition, e.g. detection and recognition of details, patterns and objects [5]. In summary the central vision answers the question "What is there?" [7].

For accurate foveal vision a well lighted object with high contrast is required [7], though too much luminance decreases the contrast. An object can only be perceived if the difference in brightness of object and background is greater than the *minimum perceptible brightness* [8]. At night the illumination is less than in daytime that is why objects are more difficult to distinguish in darkness [8]. For determination of the *minimum perceptible brightness threshold*, see figure 2 [8], the Blue-Stone method was used by Saito et al. [8]. The object illumination is decreased if the observer could identify where the object is, and increased otherwise. The threshold of the minimum perceptible brightness depends on the adaptation brightness which is the average brightness of the immediate surrounding area [6]. The brightness threshold also depends on the angle from the
fovea to the object. With a high angle the threshold increases and this trend is stronger with high adaptation brightness [8]. The adoption level of the eye controls the light sensitivity. The level is adjusted to the highest illuminated spot on the retina [2]. The adaptation to maximum light sensitivity takes approximately 30 minutes, while the opposite takes about 1 minute.

Change detection is dependent of attention and changes in low level features i.e. motion-, colour-, luminance-, position and presence changes [9, 10]. A change blindness can occur if the object is moving too slowly or if a visual distraction arises.

The perception received by the left side of the retina is connected to the right part of the brain [2]. If the two sides of the retina get different information the right part of the brain, the left side of the retina, is dominant. If the information is similar but complex and demands associative analysis the left side of the brain

**Fig. 1.** Properties and capacities of the visual field and definition of terms, based on an illustration in [2]

**Fig. 2.** Minimum perceptible brightness threshold dependent on eccentricity and adaptation brightness, based on a figure in [8]
has more capacity, i.e. the right side of the retina is dominant. This means that
text information should be presented on the right side [2].

3 Visual Field and Workload

The visual field size is the size of the visual field where a stimulus can be de-
tected without head or eye movements, i.e. with one eye fixation [9]. The ability
to discern and identify information depends on the sensitivity within the visual
field size. This sensitivity within a visual field size is called the visual field per-
formance. Reaction time can be used to determine this sensitivity though high
reaction time implies high sensitivity. Visual field performance is superior in the
region from the fixation spot out to approximately 5 degree from the fovea [5]
and it is dependent on the workload of the foveal vision. Reduction of visual
field size is directly related to the reduction of the visual field performance. [9]
This field size is for instance reduced as a function of age [11].

A high cognitive work load can cause a reduction of the peripheral vision [5].
Peripheral performance also depends on the nature of the task [12]. A general
rule is that the acuity decreases with a higher cognitive load. In an experiment
by Plains [12] foveal accuracy performance (percentage of correct responses) de-
creased with higher foveal task load when stimuli were moved further out in the
periphery. The peripheral vision can furthermore be reduced with high g-forces,
high speed or high information load [2]. In a stressed situation the color vision
can be lost and tunnelling occur. Tunneling is a reduction of detection perfor-
ance during fixation [9, 10]. A reduced distribution of eye fixations is referred
to as gaze concentration, e.g. when fixing the gaze on a spot [9, 10]. Such a high
proportion of gaze concentration causes less peripheral acuity and reduced detec-
tion performance, that can be referred to as tunneling. Both gaze concentration
and visual field performance occur as a consequence of high workload [9, 10].
The workload is higher for a beginner which means that more experienced users
possibly can make better use of peripheral vision. An observer can be trained to
see further in the periphery [7], but when a complex situation occurs the field
will still be reduced.

Two models of peripheral accuracy are the general interference model and
tunnel vision, see figure 3. In the general interference model the peripheral ac-
curacy, i.e. the peripheral task performance, is reduced equally over the whole
eccentricity with increased workload. This implies that the visual field size is
reduced as well. The results that support the tunnel vision theory only show a
reduction of the visual field size [9, 10] and not the accuracy.

4 Colour Vision

The rods in the eye are used for night vision and react well in low illumination
[2]. These have the highest sensitivity for short wavelength i.e. blue light. The
reaction time is shortest for a wave length of 380 nm; that is in-between the
invisible UV-radiation and the colour violet. In contrast to the rods, the cones
Fig. 3. Two models of peripheral accuracy and how they are affected by high workload, based on a figure in [9, 10]. General interference to the left and tunnel vision to the right. The eccentricity dimension describes how far out in the periphery information is presented.

serve to identify colours and sharp contours. High illumination is needed and the cones are most sensitive for long wavelengths. The amounts of cones and rods are, respectively, 6 and 120 millions [13]. There are three types of cones with sensitivity for different wavelength; 445 nm (violet), 535 nm (green) and 575 nm

Fig. 4. Human colour sensitivity for the right eye, based on a figure in [13]
(yellow) [14] and all the three types of cones have high distribution in the foveal vision, though the distribution differs in the further retina [13]. Colour blindness is genetic incapability to discriminate colour because of a defect in one of the types of cones. In Europe 8% of the males and 0.5% of the females have some sort of colour blindness where the inability to distinguish red and green is most common. Some people have difficulties to distinguish blue and yellow but this is very unusual. Ima et al. [15] claims that it is possible that yellow light and red light can be confused in peripheral vision because they are close to each other in the colour spectrum. How colours are discriminated in a normal visual field is showed in figure 4, where it can be seen that in the outer limit only grayscale
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is detected [13]. The colour sensitivity depends on if the eye is dark or light adapted, see figure 5 [2]. This is because of the different properties of the cones and rods. Figure 5 also shows the visible colour spectrum that is 380-760 nm in air for a human [13].

![Human Colour Sensitivity Diagram](image)

Fig. 5. Human colour sensitivity in a dark-/light adapted eye, based on a figure in [2]

In a study mentioned by Ima [16] the peripheral colour vision was investigated and the result showed that the most preferable colours in foveal vision; red and green [16], were no good out in the periphery. Instead blue and yellow give the best performance in recognition. In another study mentioned by Ima [16] red, green and blue were compared in the periphery and in 50 % of the cases red could not be distinguished from green. The same study proved that blue was the most effective colour used in peripheral vision. These results are not surprising if we consider the fact that foveal vision is most sensitive for long wavelength, i.e. red, and peripheral vision for short wavelength, i.e. blue [2]. A problem with using blue colour is that the lens of the eye is unclear and cause light-spreading which can cause dazzle, especially for short wavelengths [2]. This problem increases with age.

5 Peripheral Vision

The main function of the peripheral vision field is light and movement detection which is important for; warning detection, our ability to move and orientate in the spatial room [5]. Peripheral vision finds unusual and irregular stimuli that triggers an eye movement [9, 10]. Peripheral vision can be described as a visual alarm clock that registers motion and changes in the surrounding environment which can be a subject for a visual fixation for better identification [5]. Information retrieval in the periphery does not have to be sharp or have high contrast and works well even in poor illumination [7].

Peripheral vision is often referred to as the ambient mode of vision which answers the question of "where" the observer is in space and if the "observer or
the surrounding environment is moving" [17]. In an experiment mentioned by Charabarty [17] it is shown that the balance of a person is reduced if a cylindrical tube is placed in front of the eyes to block out the peripheral vision. While doing the opposite, reducing the central vision it was easy to maintain balance. The ambient vision also gets information from the "vestibular, somatosensory and auditory sense" for maintenance of "spatial orientation, posture and gaze stability" [17].

Visual stimuli from the peripheral visual field is obtained 90% unconsciously [16]. Unawareness is tightly coupled with peripheral vision, instinctively you can orientate without high awareness [5]. You can for example walk and read a book at the same time. Samuelsson et al. claims that peripheral vision is good at discovering unpredicted events [5]. In another experiment mentioned by Charabarty [17] a person could determine if a platform ended while reading a book, but not in the case where the peripheral vision field was occluded by special goggles. Peripheral vision has the ability to tell approximately where an object is in the spatial room [5]. The peripheral vision takes advantage of the fact that objects in the outer area of the visual field moves faster than the one in focus for direction and speed decision [5].

The distribution of the photoreceptors in the human retina causes reduced sensitivity in the peripheral retina [12]. The fovea has an increased density of receptors that makes peripheral vision more uncertain and limited [9, 10]. Visual acuity is reduced with 70% at 5 degrees from the fovea, and with 90% at 20 degrees compared to the foveal accuracy. This is not only a biological effect though the peripheral vision gets a reduced proportion of cortical processing. Peripheral vision is more sensitive in low lightening than the foveal vision because of the properties of the rods and cones [9, 10]. Periphery is sensitive for illumination changes and high luminance is easier to detect in the periphery than weaker light intensity [5]. Peripheral vision works better than the foveal vision when the retinal image is blurred. [17].

![Eccentricity and acuity in the visual field](image)

**Fig. 6.** Eccentricity and acuity in the visual field, based on a figure in [4]

The relation of eccentricity and acuity in the visual field [4] is showed in figure 6. Information can be enlarged as a compensation of visual acuity loss.
when they are presented further in the periphery. In an experiment by Anstis [18] the minimum discrimination size for letter recognition was found. The letter size was increased with 0.042 degrees for every eccentricity degree. Letters were presented within 4-55 degrees from the gaze point and the best fitting regression line for letter size is given by; 0.046eccentricity - 0.031 degrees. This regression line was only suited for presentation of a single letter. If multiple letters are presented discrimination is affected by lateral masking, i.e. "irrelevant surrounding contours" [4]. Figure 7 show letters with ten times enlargement of their threshold size [18].

![Figure 7](image)

**Fig. 7.** All letters can equally be identified when the centre is fixated, based on a figure in [18]

In a study by Nilsson et al. [19] the ability of the peripheral vision during a visually demanding task was investigated. Two static signs and two directions of moving lights should be identified by the observer. The information was presented randomly on two locations, up and down, with an average of 26 degrees. The task was to interpret the information through peripheral vision and to avoid fixation. Eye-tracking was used to distinguish if the observer was fixating on the information or not. 95% of the information retrieval used peripheral vision. Only the moving light was sufficiently identified. 25-30% failed to identify the fixed sign, according to Nilsson the reason might be that it was harder to distinguish the fixed information from each other. Another reason to that the fixed information got insufficient results could be that the two different types of fixed information were not presented in distinct locations. The fixed sign was also sensitive for visual and cognitive complexity. The fixation amount increased with low workload. The study does not tell anything about how the observers should act if they were told not to fixate on the presented information. Nilsson suggests more research on how observers interpret information from peripheral vision in real situations.
In another study by Falkmer et al. [20] the moving light was presented randomly in four locations, up, down, left and right, with an average of 18 degrees. The right and lower located displays had shortest reaction time. The upper display got fewer fixations than the right and the lower placed display.

6 Peripheral Vision Displays

Peripheral vision displays are currently used to a small extent, primarily in the air force industry. The main idea for development of Peripheral vision displays is to investigate how we can interpret information without affecting the focused attention to the primary task, that often is critical. It is important to think about the situation when designing a system where information retrieval could be unaware and affect users’ actions [5]. The peripheral vision uses a lower degree of awareness that makes it possible to present information in a way where it is perceived more or less unconsciously [5]. Empirical results have showed that the use of peripheral vision cues reduces the foveal vision overload and simplifies human machine communication and coordination [16]. The time to refocus from the primary task to a regular display, designed to be interpreted with foveal vision, is presented in figure 8 [13]. A Head Up Display, HUD, is used to present information e.g. on the windshield of an aircraft. It serves to minimize this focus shift [5] is therefore not a peripheral vision display by default, even if it has good potential to be one.

Peripheral vision display can take many different forms, here follows one example for text presentation and two examples that uses light for awareness and guidance.
6.1 Agricultural guidance system

A peripheral vision display developed by Young et al. [21] was used to maximize the efficiency of agricultural production. The system helps the driver to optimize the course through the field by presenting GPS data. This was accomplished by using an enlarged light-bar which could be interpreted with the observer’s peripheral vision, see figure 9, instead of the more commonly used smaller light-bar, see figure 10. The light-bar lights up in the centre if the steering path is correct and to the right or left if a steering-error occurs. The steering-error decreased when this enlarged light-bar was used instead of the small light-bar. An experiment by Ima et al. [15] showed that the increased size of Light Emitting Diodes, LEDs, in an agricultural guidance system reduced the steering error with 10% and reaction time with 4%. In the same experiment the agricultural guidance system was tested with different colours on the LED’s and the result showed that blue colour decreased the steering error with 14 % and reaction time with 13% compared to using red colours.

Fig. 9. A light-bar designed for peripheral vision used in an agricultural guidance system with 16 LEDs in each cluster and a total size of 46 mm x 1420 mm, based on a picture in [21]

Fig. 10. A traditional GPS guidance aide with 23 LEDs and a total size of 5 mm x 180 mm, based on a picture in [21]

6.2 Flight Deck Systems

Ima et al. [16] mentioned that Nikolic and Sarter found, in two different peripheral vision display implementations of a flight deck system, that the detection rate and response time were improved without interference with the primary visual task. Empirical evidence also shows that peripheral vision displays are good at supporting continuous tasks [15] i.e. spatial orientation in an aircraft.
The **Forward view symbiotic display** is another flight deck system designed by Charabarty [17]. Two vertical light-bars were installed inside an aircraft cockpit, see figure 11. These light-bars indicated the roll of the aircraft by lightening up LEDs to visualize the horizon. The pilot could draw a line between the two light-bars and create a virtual horizon. Colours were used to indicate the roll angle of the aircraft; green for straight forward, red for maximum tilt, and amber up to 25 degrees. The right light-bar could not be seen in the periphery of the pilot which meant that the pilot could not create the virtual horizon even though the light-bars succeeded in providing guidance.

### 6.3 Text presentation

The technique described earlier by Ansits with increasing letter size can be used for text presentation. Victor and Jarlengrip [22] invented and patented solutions that are using this technique in combination with eye- and head positioning for information presentation in vehicles. One solution is showed in figure 12 where text is presented onto the dash board and is enlarged with respect to increasing distance from the gaze point.

### 7 Design of Peripheral Vision Displays

Following section describes difficulties in designing information retrieval using peripheral vision. This section is followed by design guidelines and heuristics that must be taken in concern when designing peripheral vision displays.

#### 7.1 Difficulties in Designing Peripheral Vision Displays

If the design fails as a peripheral vision display, it can take even more resources instead of realising resources from central vision. Usually a periphery stimulus
reflexively causes a new eye fixation towards the stimulus [5] and this is a challenge when designing peripheral vision displays. This property is on the other hand well suited for directing attention to a critical task. It could be hard to relearn and not shift focus to the information presented in the periphery. If peripheral vision displays used in a critical situation it is possible that distraction by the display occurs [5].

If the user cannot take attention away from the primary task then information presented in the periphery can easily be missed [5]. To insure that information is not neglected; the placement of the information should be within five degrees from the fixation point where 90% of presented information can be interpreted, i.e. in the central vision. Five degrees corresponds to a surface with a diameter of 17 cm a distance of 1 meter.

7.2 Paradigms and Heuristics

- Peripheral vision is best used for detection of changes of light and movement. Visualization techniques that not take advantage of these properties should be avoided, e.g. colors, small details changes, text, and thin arrows pointing at different directions [5].
- Presented information should have a low degree of visual complexity and have a simple and distinct form [5]. Furthermore, use a few, large, simple and distinct icons which are easy to separate and interpret.
- The peripheral vision can to a certain extent recognize the shape of an object e.g. if it’s a rectangle or a triangle [5].
- In a study mentioned by Samuelsson [5] letters can be detected better further out in periphery than drawings of objects.
- A double size enlargement of a symbol results in a corresponding increase in performance of how well the user interprets the information [5]. An increased object size, while using peripheral vision also makes the contrast sensitivity better [15].
The information must be presented at the same place and should preferably be well separated from places where other information is presented. [5]

Because of the reduced peripheral sensitivity a light must have higher intensity to be detected in the periphery instead of with foveal vision [12].

The designer should give different light and movement changes a meaning when designing peripheral vision displays [5].

Horizontal movements are easier to detect than vertical [2].

The functionality should not only rely on colour-codes. Avoid information visualization through colour-codes and avoid the colours red and green. Colour blindness is common and the peripheral visual field is not so good at distinguishing colour.

An observer prefers to look downwards and the eyes prefer to rotate downwards rather than upwards [16]. The placement of peripheral vision displays should accordingly be well below the primary display and be placed more than 15 degrees below the horizontal eye level [16].

A right or lower located display have the shortest reaction time. The upper display gets fewer fixations than a right or lower placed display.

In a foveal attention-rich environment the need to reduce the fovea load is high. Recourses can therefore be released by using peripheral detection.

Avoid presenting information in the periphery when the primary task needs high attention, or when a complex situation occurs [5].

Information presented in the periphery can be missed in a critical situation if the presentation is not done in an appropriate way. Present information closer to the foveal vision for awareness in an unexpected situation.

Sound can identical to peripheral vision direct a reflexive eye fixation towards a stimuli and is good at catching and directing attention. An appropriately designed 3D-sound should be distinct, intuitive and realistic [23].

**8 Summary and Conclusion**

The purpose of well designed peripheral vision displays is to release resources from central vision. In conclusion information presented in the periphery is more sensitive for bad design choices than information presented in central vision. This is because visual performance, cognitive and visual overload makes it hard to distinguish and interpret necessary information. How easy peripheral vision information can be interpreted depends in summary on [19]:

- Human ability
- Presentation e.g. shape and colours
- Timing e.g. when to present
- Placement

These aspects can also be applied for regular information visualization but with another meaning. Peripheral vision and central vision serve different purposes and therefore the design principles differ.
References


Peripheral vision, or indirect vision, is vision as it occurs outside the point of fixation, i.e. away from the center of gaze. The vast majority of the area in the visual field is included in the notion of peripheral vision. "Far peripheral" vision refers to the area at the edges of the visual field, "mid-peripheral" vision refers to medium eccentricities, and "near-peripheral", sometimes referred to as "para-central" vision, exists adjacent to the center of gaze.