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Visual Attention Distribution According to Size, Color, and Spatial Location of Stimuli under Foveal and Peripheral Vision Conditions

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Abstract

Visual attention allows individuals to select the information most relevant to ongoing behavior. Attention mechanisms serve two critical roles. First, attention can be used to select behaviorally relevant information and/or to ignore irrelevant or distracting information. Second, attention can modulate or enhance the selected information according to the perceiver's state and goals. With attention, perceivers are more than passive receivers of information. They become active seekers and processors, able to interact intelligently with their environment. Among the characteristics of visual stimuli, size can refer to the spatial extent of an item. Searching for the largest item is particularly efficient. Regarding color, it has long been accepted as a pre-attentive feature.

The aim of our research was to determine the importance of three characteristics of a visual object – size, color, and location in the visual field in the process of attention distribution under central and peripheral vision conditions. The study consisted of two series: in the first, the subjects performed the given task without reading any text; in the second, they performed the task while reading a running text. The study involved 40 volunteers of both sexes, aged 20 to 40 (mean age ± 32), with normal or corrected vision (visus > 0.8). All participants were right-handers and left-

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to-right readers. Gender distribution was balanced, and all participants were right-handed and left-to-right readers.

In the no-text experiment (without additional information), when foveal information is scarce, attention distribution based on the size of the stimuli is more refined, and such stimuli are detected faster than in the text experiment (with additional information), where foveal information plays a more significant role. In both the no-text and text experiments, yellow and red stimuli are detected faster than green and blue. We assume that when perceiving a scene, the eye begins moving from the upper left corner to the lower left area, then to the lower right, and finally to the upper right during the no-text series, when focal information is scarce. Apparently, regardless of stimulus parameters and the intensity of the information flow, stimuli located in the upper left corner of the scene are perceived faster. This may be due to the habitual left-to-right reading pattern, or one can also pay attention to the phenomenon of pseudoneglect, which is often left-sided.

Keywords: Attention, foveal vision, peripheral vision, size, color, location of stimuli

Introduction

General ideas about how a person perceives, senses, and understands the world have existed since ancient times. It is not surprising that visual perception has received special attention from the very beginning, as the visual system undoubtedly plays a leading role among the human sensory systems, both in terms of the volume of information processed and its biological significance.

When searching for necessary objects within scattered images in the visual field, attention distribution becomes crucial. It is often necessary to notice or distinguish the most important objects in the visual field within a very short time. If the objects being searched for differ in several characteristics simultaneously (e.g., color, size, shape) and also change the location within the visual scene, it becomes important to determine which of these characteristics our eyes prioritize, that is, which ones our visual system responds to faster. Many cognitive processes start with visual information processing via the retina. However, visual perception across the retina is not uniform – it is sharpest at its center, the fovea, and decreases with increasing eccentricity (Loschy et al., 2005; Rosenholtz, 2016). Typically, we are only aware of the most salient parts of a visual scene or the parts we are actively paying attention to. These are generally the areas that contain the most important information. What role does the salience of the observed visual stimuli play? Wolfe outlines the types of features that humans can detect ‘efficiently’ and that might be considered salient within an image: color,

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orientation, curvature, texture, scale, Vernier offset, size, spatial frequency, motion, shape, onset/offset, pictorial depth cues, and stereoscopic depth (Wolfe,1998).

Visual attention allows individuals to select the information most relevant to ongoing behavior. As the data have shown, attention mechanisms serve two critical roles. First, attention can be used to select behaviorally relevant information and/or to ignore irrelevant or distracting information. Second, attention can modulate or enhance the selected information according to the perceiver's state and goals. With attention, perceivers are more than passive receivers of information. They become active seekers and processors of information, able to interact intelligently with their environment (Marvin, & Wolfe, 2000).

Among the characteristics of visual stimuli, size can refer to the spatial extent of an item. There is good evidence for the featural status of size in this sense. Searching for the largest item is particularly efficient (Bilsky, Wolfe & Friedman-Hill, 1994; Dehaene, 1989). Regarding the color, it has long been accepted as a pre-attentive feature (Bundesen & Pedersen, 1983; Carter,1982; Farmer & Taylor, 1980). When searching for different colors, some may appear more basic than others. For example, purple may be represented as red and blue in the pre-attentive guidance of attention (Moraglia, Maloney, Fekete & Al-Basi, 1989; Treisman, 1985).

The evidence suggests that focal attention can be directed to one or, perhaps, a few objects at a time. However, the number of potential targets for attention in a visual scene usually far exceeds that number. The informational load of the object receiving focal attention is of particular importance.

Moreover, the focus of attention may be influenced by the overall load of difficulty of a task. For attention to remain focused on a target, the overall perceptual load must be sufficiently high to prevent any remaining capacity from being diverted to non-target events. In the absence of a sufficiently high load, attention tends to spill over to non-target events (Kahneman & Chajczyk, 1983; Lavie, 1995; Lavie & Tsal, 1994).

The spatial distribution of attention follows a gradient, with attention effects decreasing as eccentricity from the focus increases (Downing & Pinker, 1985; Eriksen & Yeh, 1985; Hoffman & Nelson, 1981; LaBerge, 1983; Shaw & Shaw, 1977). The efficiency of a visual search can be assessed by measuring performance changes – typically reaction time (RT) or accuracy – as a function of changes in "set size," or the number of items in the display.

Observers react faster to objects that appear in the attended region than to those in unattended regions (Eriksen & Hoffman, 1972; Posner, 1980). They also respond faster to a stimulus of an expected size than to one of an unexpected size (Larsen & Bundesen, 1978).

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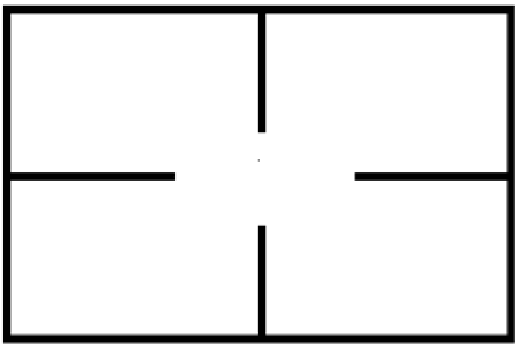
A particularly significant finding is that stimuli presented to the left and upper areas of the fixation point were identified more accurately than those presented to the lower right (Klatt & Schrödter, 2024).

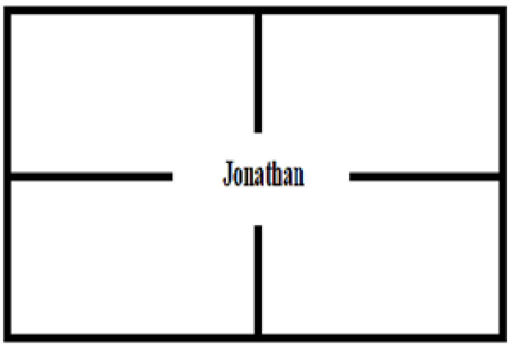
The spatial advantage of the upper-left visual quadrant aligns with the pseudoneglect phenomenon described by Bowers and Heilman (1980) and further explored by Marinelli et al. (2019), who linked it to reading direction Research on attention distribution concerning the color of objects and their location in the visual field is rare. Therefore, we set a goal to study attention distribution to three characteristics of a visual object – size, color, and location – and the role that central vision and peripheral vision play in this process.

Methods and Design

The study involved 40 volunteers of both sexes, 20 women, 20 men, aged 20 to 40 (mean age ± 32), with normal or corrected vision (visus > 0.8). All participants were right-handers and left-to-right readers. The experiment recorded and analyzed the subjects' reaction times in response to three parameters of visual stimuli: size, color, and location of appearance on the monitor screen. The study consisted of two series: in the first **(A)**, the subjects performed the given task without reading any text; in the second **(B)**, they performed the task while reading a running text.



A.



B.

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The subject was sitting in front of a computer (SyncMaster 997 MB) monitor screen at a distance of ~ 60 cm, in a darkened room (illumination: 0.5 lux). The screen was conventionally divided into 256 virtual squares (16×16), excluding the fixation area. According to the special program, stimuli (circles) of different sizes (2, 3, 4, 5, 6, 7, and 8 mm in diameter) and colors appeared in these squares in random order – red (R-255, G-0, B-0), yellow (R-255, G-255, B-0), blue (R-0, G-0, B-255), and green (R-0, G-255, B-0). Each size and each of the four colors –7 × 4, a total of 28 combinations – were presented to each subject in random order, 10 times each.

The duration of each presentation of colored stimuli in the above sizes was 0.5 seconds, and the total duration of each series was 140 seconds. The task was as follows: a white oval spot (angular size – 1.42˚) appeared in the center of the screen, representing the fixation area of vision. The subject was required to confirm noticing a colored stimulus by pressing any key on the keyboard when it appeared anywhere on the screen. The location of each stimulus was registered in the program protocol using **X** and **Y** coordinates. The program also recorded the reaction time **(RT) –** i.e., the time between the stimulus appearance and the key press. **RT**s for all three parameters were recorded separately for each subject. The average **RT** values for the presented stimuli were used to determine the speed of stimulus perception. In the first series of the experiment, the task was performed without any additional informational load – only a white oval spot appeared in the center. In the second series, a running text unfamiliar to the subjects (a fragment from the Georgian translation of Richard Bach's *Jonathan Livingston Seagull*) appeared on the white oval spot. The subject was required to read the text aloud while continuing to press any key when stimuli appeared in various areas of the screen. In both series, the program recorded the **RT**s for each subject by the size, color, and location of the stimuli. A 2-minute interval was provided between the no-text and text-containing series, during which the subject rested. Reaction times recorded during the experiment were statistically processed using a **t-test** according to the three parameters: stimulus size, color, and location of appearance on the screen.

The Results of the Experiments

The data of the research - RT in the without-text reading and with-text reading series of the experiment were as follows:

RT according to the sizes of stimuli:

The differences in stimulus detection times by size are reliable when comparing the conditions without text reading and with text reading. As expected, in the without-text reading series, subjects detected stimuli faster than in the with-text reading series ($P < 3.8876E-23$). In both the without-text-

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reading and with-text-reading series, stimuli measuring 6–7–8 mm were detected faster than the others (P < 0.0017 in the without-text-reading series and P < 0.003961 in the with-text-reading series). (Fig. 1).

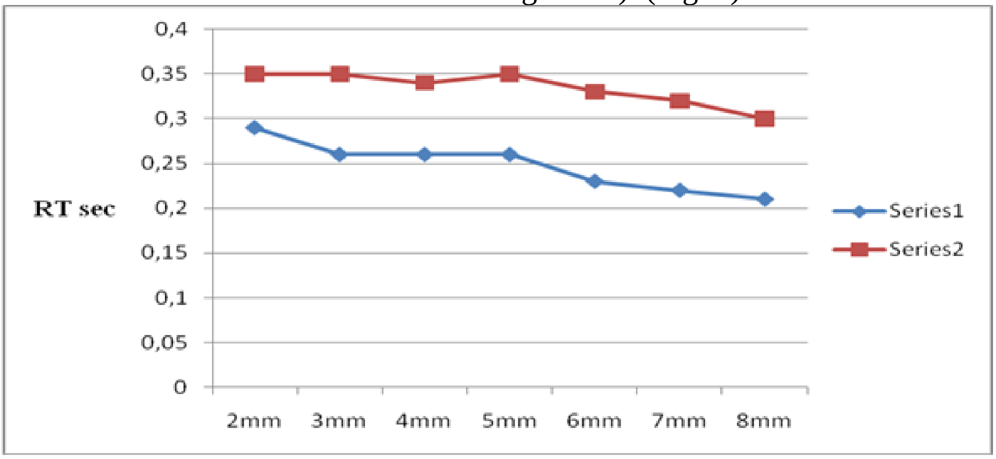

Fig. 1. Average reaction times depending on stimulus size:
Series 1 – without reading the text; Series 2 – with reading the text.

When comparing the results of the without text reading and with text reading series separately by color, we see that the average RT for stimuli differs more when blue (P < 9.62937E-95) and red (P < 5.3498E-07) stimuli appear than when yellow (P < 0.00019) and green (P < 0.0015) stimuli appear, although the differences are statistically significant in all cases. (Fig. 2 A).

RT according to the colors of stimuli:

In the without-text reading series, the average RTs for all given-size red and yellow stimuli (0.21 sec for both) were significantly shorter than the average RTs for all given-size blue (yellow vs. blue: P < 0.0493; red vs. blue: P < 0.0282) and green stimuli (yellow vs. green: P < 0.026485; red vs. green: P < 0.01484). The average RTs for all given-size blue and green stimuli were 0.25 and 0.26 sec, respectively. The differences between the average RTs for all given-size yellow-red (P < 0.3824) and blue-green (P < 0.3594) stimuli were not statistically significant. A similar pattern was observed in the with text reading series. Here, the mean RTs for all given-size red and yellow stimuli (0.32 sec for both) were significantly shorter than the mean RTs for all given-size blue and green stimuli (0.34 and 0.35 sec, respectively). There were also significant differences when comparing the mean RTs for the yellow-blue (P < 0.0038), red-blue (P < 0.0292), yellow-green (P < 0.0068), and red-green (P < 0.0466) stimuli. Again, the data were statistically insignificant when comparing the mean RTs for the yellow-red (P < 0.1524) and blue-green (P < 0.4593) stimuli. (Fig. 2 B).

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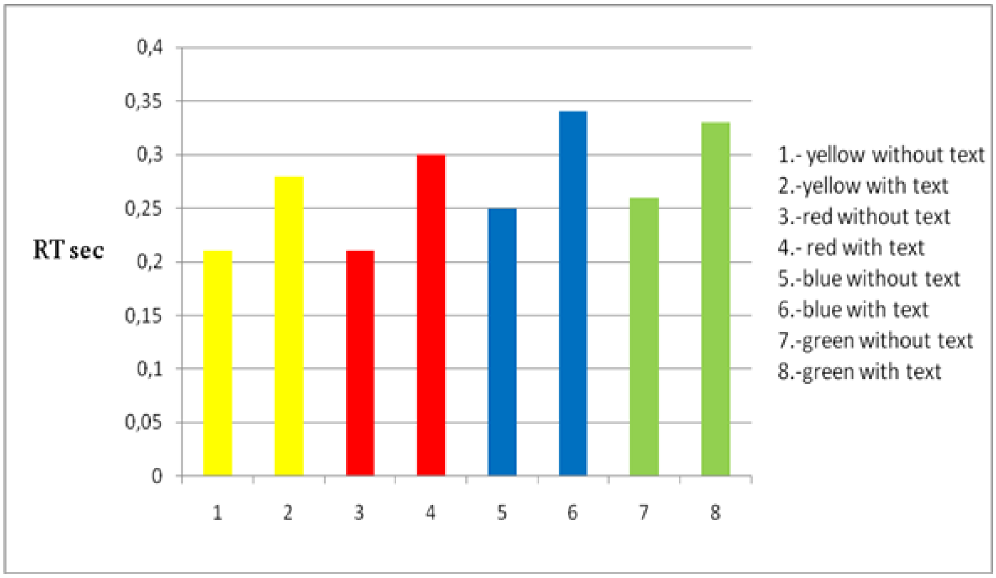
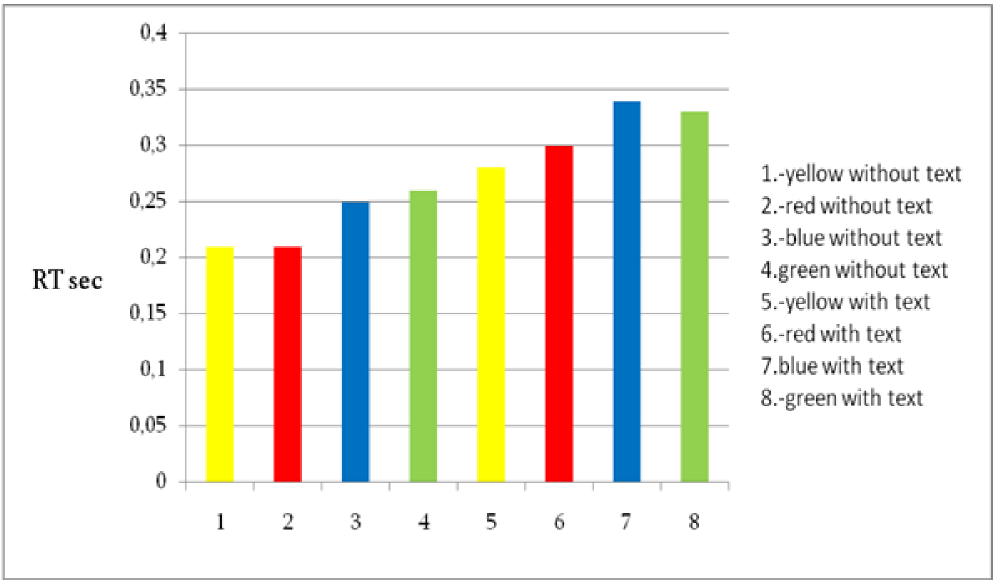


A.



B.

Fig. 2: RT of the stimulus detection in the visual field duringreading without text and text reading:

A. 1 - yellow without text, 2 – yellow with text (p<0,00203); 3 - red without text, 4 – red with text (p<4,31694E-06); 5 - blue without text, 6 - blue with text (p<0,00012); 7 - green without text, 8 – green with text (p<0,0021).

B. Comparative analysis: 1,2,3,4 – yellow, red, blue, green stimuli detection RT – without text reading; 5,6,7,8 – yellow, red, blue, green stimuli detection RT – with text reading.

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Without text reading (yellow-red p<0,382459; red-blue p<0,028226; blue-green p<0,359423; yellow-blue p<0,049369; yellow-green p< 0,026485; red-green p<0,01484).

With text reading (yellow-red p<0,152381; red-blue p<0,02921; blue-green p<0,459373; yellow-blue p< 0,003754; yellow green p< 0,006786; red-green p<0,046553).

RT according to the locations of stimuli in visual space:

It was found that, on a monitor screen divided into 256 squares, in the without text reading series, subjects perceived the stimuli appearing in the 21st (0.16 sec), 53rd (0.16 sec), 69th (0.15 sec), 97th (0.14 sec), 103rd (0.15 sec), 118th (0.15 sec), 77th (0.16 sec), 145th (0.16 sec), 178th (0.15 sec), 247th (0.15 sec), 139th (0.15 sec), and 220th (0.13 sec) squares the fastest. Of these, squares 21, 53, 69, 97, 103, and 118 are located in the upper-left quadrant of the screen, with an average RT of 0.22 seconds in this quadrant. Square 77 is located in the upper-right quadrant, with an average RT of 0.25 seconds. Squares 145, 178, and 247 are located in the lower-left quadrant, with an average RT of 0.24 seconds. Squares 139 and 220 are located in the lower-right quadrant, with an average RT of 0.25 seconds.

When comparing the average RT values for the stimuli appearing in the above-mentioned squares with those in the with text reading series, it is clear that stimulus perception in the without text reading series occurred faster than in the corresponding areas of the with text reading series: 21st (0.35 sec), 53rd (0.31 sec), 69th (0.38 sec), 97th (0.33 sec), 103rd (0.35 sec), 118th (0.34 sec), 77th (0.31 sec), 145th (0.27 sec), 178th (0.32 sec), 247th (0.26 sec), 139th (0.49 sec), and 220th (0.27 sec). In the with text reading series, the average RT values were nearly identical across all four quadrants: 0.30 sec (upper left), 0.30 sec (upper right), 0.31 sec (lower left), and 0.31 sec (lower right). (Fig. 3).

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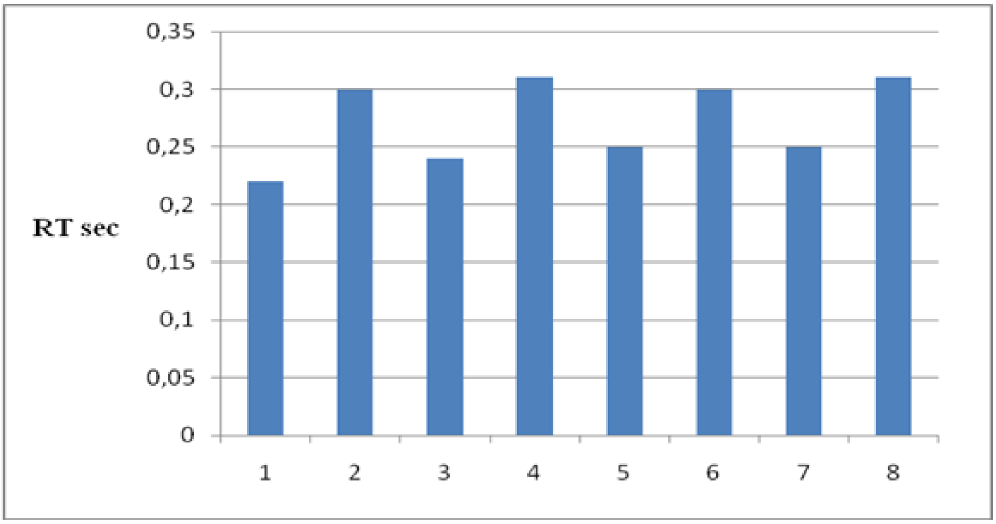

Fig. 3: The time of detection of stimuli in the different areas of the monitor's screen: 1.– left upper area (without text reading); 2. - left upper area (with text reading); 3. – right upper area (without text reading); 4. - right upper area (with text reading); 5.– left bottom area (without text reading); 6. - left bottom area (with text reading); 7 – right bottom area (without text reading); 8 - right bottom area (with text reading).

Discussion

The results show that in visual perception, the amount of information load in central, foveal vision plays a crucial role. When foveal information is minimal, peripheral vision detects stimuli located outside the central area faster than when the foveal load is significant.

When an unfamiliar running text was presented to the subject in the central fixation area, RT to stimuli appearing in the peripheral parts of the visual scene increased significantly (P < 3.8876E-23), compared to experiments where the only information source in the central visual field was an oval-shaped white spot.

In the without text reading experiment, the average reaction times for stimuli with diameters of 3, 4, and 5 mm were approximately the same (0.26 seconds) and significantly different from the reaction times for 2 mm stimuli (0,29 seconds) (P < 0.001898) and for 6, 7, and 8 mm stimuli (P < 0.000468).

The average reaction times for 6, 7, and 8 mm stimuli did not differ significantly from each other (P < 0.108189). The shortest reaction time (0.21 seconds) was observed for 8 mm stimuli, which was significantly different from the average reaction times for 3, 4, and 5 mm stimuli (P < 0.006205). Additionally, the enhanced detection of larger stimuli supports research by Bilsky et al. (1994), who emphasized the efficiency of size-based searches. Reaction times were less varied in the text reading series of the experiment. Here, two main groups emerged: 2, 3, 4, and 5 mm stimuli (with reaction times of 0.35, 0.35, 0.34, and 0.35 seconds, respectively), and 6, 7, and 8 mm stimuli

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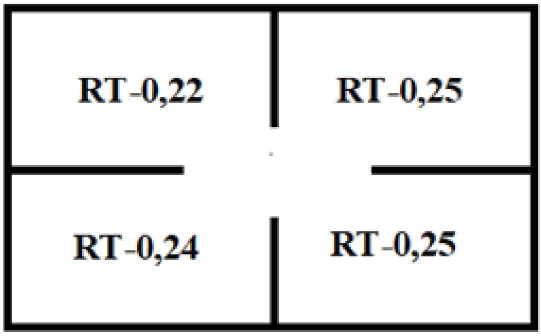
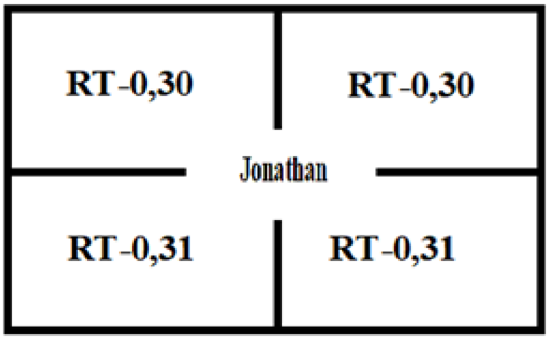
(with reaction times of 0.33, 0.32, and 0.30 seconds, respectively). This suggests that attention distribution is more subtle when foveal information is scarce, compared to when it carries more weight.

If we disregard the size of the stimuli and estimate RT only by color, subjects also took longer to detect stimuli in the with-text reading series compared to the without-text reading series. In both cases, red and yellow stimuli were noticed significantly faster than blue and green ones. Again, the presence of foveal information influenced the speed of peripheral perception.

Regarding the location of stimuli on the monitor screen, a comparison of RTs in the without-text-reading series reveals a noticeable difference: responses to stimuli in the upper left quadrant were significantly faster than those in the lower left, upper right, and lower right quadrants. This suggests that, under conditions of minimal foveal load, peripheral perception tends to begin in the upper left visual field.



In the without text reading series, the results for the lower left, upper right, and lower right quadrants were nearly identical. In contrast, the text reading series showed no significant differences between any of the quadrants.



This likely indicates that when foveal information is abundant, no specific area is prioritized during peripheral perception.

At the same time, the tendency of peripheral vision to begin in the upper left visual field may be ascribed to the attentional bias towards the left visual hemifield, known as “Pseudoneglect.” This phenomenon is expressed

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on a group level in most adults and children (Bowers, Heilman, 1980; Rinaldi et al., 2014) and is better expressed in left-to-right readers in comparison to right-to-left readers (Marinelli et al., 2019; Muayqil et al., 2021; Makashvili et al., 2024).

Although the results are statistically robust, the study has some limitations. The sample size was limited to 40 participants, all between 20 and 40 years of age, right-handed, and left-to-right readers. Therefore, the results may not fully generalize to younger or older individuals, left-handed participants, or those from cultures with right-to-left reading habits. Moreover, individuals with visual impairments or attentional disorders were not included, which could limit the broader applicability of our findings.

Conclusions

1. The average reaction times in the without-text-reading series of the experiment were shorter and significantly different from those in the with-text-reading series. This difference was observed in both analyses, by stimulus size and by color. In the without-text reading series (with no additional information), when foveal information is scarce, attention is more subtly distributed according to stimulus size than in the with-text reading series (with additional information), where foveal information appears to be given greater importance.
2. In both the with-text reading and without-text reading series, yellow and red stimuli were detected faster than green and blue stimuli.
3. In the without text reading series, participants responded significantly faster to colored stimuli presented in the upper-left quadrant of the visual field than to those in the upper-right, lower-left, or lower-right quadrants. This may be related to the phenomenon of pseudoneglect and habitual left-to-right reading patterns. No such differences were observed in the text reading series.
4. These results can be useful in interface design, visual display optimization, and user experience research in environments where fast detection of visual elements is critical, such as driving, aviation, or digital media. Also, for improving the readability of advertising inscriptions.

Conflict of Interest: The authors reported no conflict of interest.

Data Availability: All data are included in the content of the paper.

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Declaration for Human Participants: This study has been approved by Beritashvili Centre of Experimental Biomedicine, and the principles of the Helsinki Declaration were followed.

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