Prior knowledge modulates peripheral color appearance

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ABSTRACT

Color perception deteriorates with increasing eccentricity in the visual field. Here, we investigated peripheral color perception using a painting method, asking how prior knowledge affects color appearance. A professional artist was presented with complex, cluttered images in the visual periphery. The task was to paint as accurately as possible how each image appeared. Eye tracking assured that the image was only viewed in the periphery. The resulting paintings were strongly compromised. After finishing a painting, the target image was freely viewed to acquire knowledge about it. Next, the same image was presented at the same peripheral location and painted again. There were two conditions for the second painting. In the first condition, the image was again masked when not fixating the fixation dot (as during the first presentation). In the second condition, the image was not masked, allowing saccades to the image. In both conditions, the paintings resulting from the first presentation showed clear differences compared to the second presentation. Salient color regions in the images that were not painted during the first presentation, were painted during the second presentation. Color changes were less pronounced in the first than in the second condition. Importantly, several image features were remembered but not painted during the second presentation, showing - in addition to subjective reports – the perceptual nature of the effect. Our results indicate that prior knowledge of peripheral targets strongly shapes perception.

1. INTRODUCTION

Color sensitivity deteriorates with increasing eccentricity (Moreland, 1972). The extent of this deterioration is still unclear. For example, it has been proposed that color vision is absent at eccentricities larger than 40 degrees of visual angle (Moreland & Cruz, 1959). However, it has also been shown that, depending on the stimulus properties, color can still be discerned at larger eccentricities, even up to 90 degrees (Noorlander, Koenderink, den Ouden, & Edens, 1983). Peripheral vision is not only characterized by diminished color sensitivity. One of the major limiting factors of peripheral vision is crowding - the deleterious influence of neighboring items on the perceptibility of a target (e.g., Levi, 2008). For example, an isolated letter that is easily recognized in the periphery is indiscernible when other letters are presented in close proximity. Crowding depends on several factors, e.g., eccentricity (Bouma, 1970), target-flanker similarity (Kooi et al., 1994), grouping (Sayim, Westheimer, & Herzog, 2010), and prior knowledge (Zhang et al., 2009). The influence of crowding on color perception is rarely investigated. However, it has recently been shown that the perception of hue and saturation deteriorates when the target is crowded (van den Berg, Roerdink, & Cornelissen, 2007). Using visual noise

(Greenwood, Bex, & Dakin, 2010), and letters and letter-like symbols (Sayim & Wagemans, 2013), it has been shown that crowding does not only impede performance but also changes appearance.

Here, we used a painting method to investigate appearance changes in complex, cluttered images, asking first, how color appearance is influenced by crowding, and second, whether knowledge about target images modulates appearance. This explorative painting method in conjunction with complex images allowed us to explore these questions simultaneously, using the entire image as a target. We found strong modulation of color appearance, and a clear influence of knowledge on target perception.

2. METHOD

We investigated peripheral color appearance with a painting method. A professional artist (the last author of this manuscript, TvU) was presented with complex, cluttered images in the right visual field. The task was to capture as accurate as possible how the image appeared.

2.1 Apparatus

Stimuli were presented on a Sony Trinitron GDM-F520 CRT monitor driven by a standard accelerated graphics card. The screen resolution was set to 1152 by 864 pixels; the refresh rate was 120 Hz. A chin and head rest was used to restrict head movements. The screen was viewed from a distance of 58 cm. Eye positions were monitored by an SR Research EyeLink 1000 running at a sampling rate of 1000 Hz. An elevated, inclined drawing board was placed in front of the head and chin rest to allow for painting without leaving the head rest. Colored crayons were used to paint. MATLAB (Mathworks, Natick Massachusetts, USA) in combination with the Psychophysics toolbox (Brainard, 1997) was used for stimulus presentation.

2.2 Stimuli

Stimuli consisted of two complex, cluttered images (Figure 1). Images were 15.0 degrees wide, 10.2 degrees high, and were presented on the horizontal midline of the screen, centered at 12 degrees eccentricity in the right visual field. The first image consisted of various shapes, such as ellipses, rectangles, and lines (the “Miro”-Image, Figure 1A, left). The second image consisted of an arrangement of rectangles with different sizes and colors (the “Mondrian”-Image, Figure 1B, left). Both images varied strongly in color and luminance. Images were presented on a gray background (50.5 cd/m^2). A fixation dot was presented at the center of the screen. To prevent central viewing of the stimulus, the target images were masked by a pattern mask of the same size as the target whenever the participant did not fixate the center of the screen (except during the second “Mondrian” painting; see Procedure).

2.3 Procedure

Each target image was painted twice. The participating artist (TvU) fixated on the fixation dot in the center of the screen. For the first painting of each image, the target image was only presented when fixating the fixation dot, otherwise it was masked. The task was to reproduce the appearance of the stimulus in as much detail as possible. After completion of the painting, the image was shown foveally for visual inspection. Next, the target image was again presented in the periphery and painted once more. In the "Miro"-condition, the target image was again only shown when fixating the fixation dot, and masked otherwise. In the "Mondrian"-condition, the target image was not masked. There was no time restriction for (peripheral) viewing of the target image, and finishing a painting, allowing the participant to focus attention on all areas of the presented target. The painting of one image took about 40 minutes.

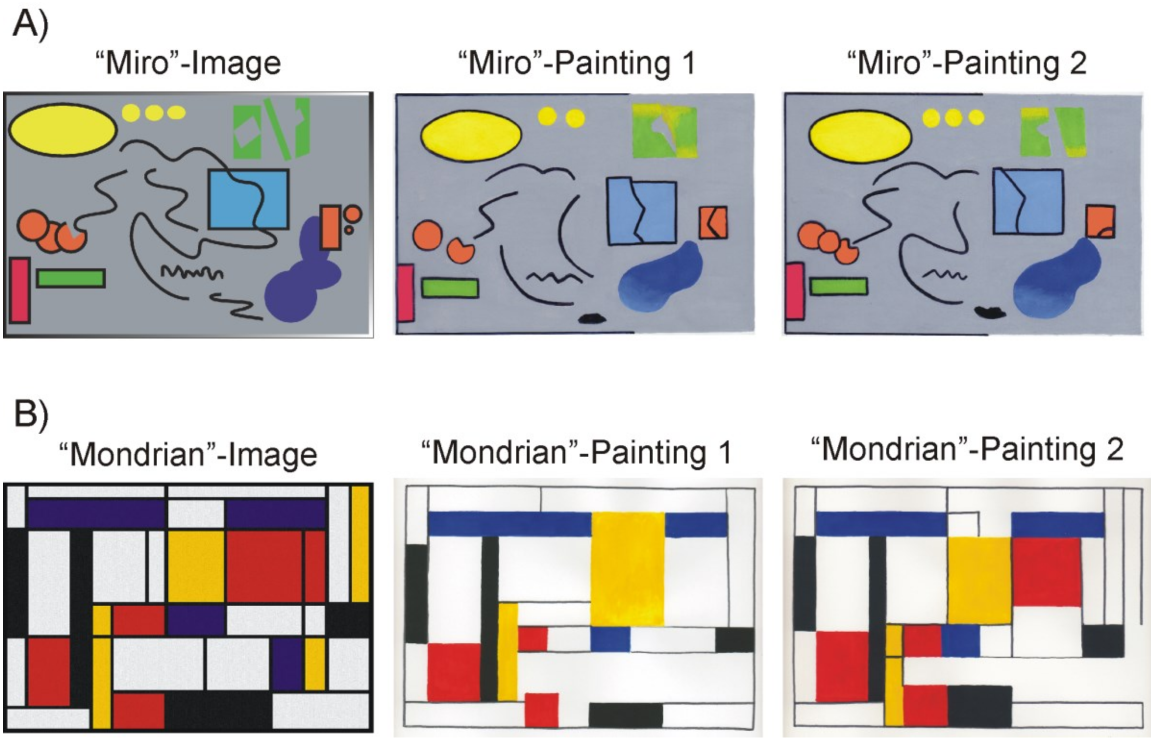

Figure 1: Original images and painting results. Target images (left column) were presented at 12 degrees in the right visual field. (A) In the "Miro"-condition, the target image was masked during the first ("Miro"-Painting 1) and second ("Miro"-Painting 2) presentation when the fixation dot was not fixated. B) In the "Mondrian"-condition, the target image was masked during the first presentation when the fixation dot was not fixated ("Mondrian"-Painting 1); during the second presentation, it was not masked ("Mondrian"-Painting 2).

3. RESULTS AND DISCUSSION

The results show a strong decrease in accuracy with increasing eccentricity (Figure 1). Sections of the target images closer to the fovea were reproduced more accurately, i.e., more similar to the target image, than sections farther in the periphery (note that due to the imprecision of the painting method, only large, categorical differences are of interest here). In the first painting of the "Miro"-Image (Figure 1A, center, "Miro"-Painting 1), several shapes and parts of shapes are depicted distorted or left out entirely. For example, instead of an orange rectangle and two orange discs (right outer edge of the painting), a single square structure was painted. However, clear differences between the target image and the painting occurred also closer to the fovea. Instead of depicting three circular/ oval items in the upper left quadrant, only two items were painted. Similarly, close to the left edge (below the horizontal midline) an empty/ gray gap was introduced between the two painted orange discs. Noticeable deviations of color appearance occurred in sections far in the periphery. In particular, uniformly colored items were depicted to contain additional hues (the green pattern in the upper right quadrant was depicted in green and yellow), or varied in regard to saturation (the bluish structure in the lower right quadrant). After free visual inspection, i.e., acquisition of detailed knowledge of the target image, the image was again presented in the visual periphery when fixating the center of the screen, and painted a second time (Figure 1A, right, "Miro"-Painting 2). The second painting was clearly different compared to the first painting. In particular, the previously missing circular/oval items were depicted in the second painting. Reports by TvU pointed at strong changes of perception compared to the first painting, e.g., "I now see clearly that there are three yellow discs". Subjective reports also indicated a general reduction of vagueness of color appearance ("the green is clearer now").

The first painting of the "Mondrian"-Image shows similar effects as the first "Miro"-Painting. Several (missing or added) white gaps, and missing regions with different hues show that peripheral color perception was compromised, again increasing with eccentricity. The two red rectangles and the yellow rectangle in the upper right quadrant, as well as the blue and yellow rectangles in the lower right quadrant are entirely missing. Subjective reports indicated that the large yellow rectangle sometimes appeared in parts orange – similar color mixtures and perceptual switching between different color categories at the same location were reported with other paintings (results not shown here). The second painting of the "Mondrian"-Image showed clear differences compared to the first. A large difference occurred in the upper right quadrant where a red square/rectangle present in the image was painted instead of a white region depicted in the first painting. Also, the number of deviating white gaps was reduced in the second painting.

Our results reveal a strong loss of accurate perception of detail which increased with eccentricity, reflecting the combined effect of crowding and reduced sensitivity in the peripheral visual field. In particular, the loss of large regions with strong color contrast are noticeable, raising questions regarding their visibility, for example, in standard detection experiments (note that crowding usually does not influence detection). Differences between the first and second paintings indicate appearance changes by knowledge, both when knowledge was only acquired between trials ("Miro"-condition), as well as between trials and during the second trial ("Mondrian"-condition). The large difference between the first and second trial in the "Mondrian"-condition (the red rectangle in the upper right quadrant), suggests that intermittent acquisition of knowledge strongly changed appearance. Importantly, several details of the images were remembered during the second paintings but not perceived and therefore not painted, indicating that perceptual changes, and not abstract memory, underlie these results. For example, the blue and the two yellow rectangles in the right half of the "Mondrian"-Image were remembered but not depicted (Figure 1B, right). The still clearly visible decrease of accuracy with eccentricity supports this interpretation, as do subjective reports regarding the perceptual nature of the appearance changes. Note that to paint the image, all regions of the image were (covertly) attended several times allowing maximum reduction of uncertainty about appearance. Similar, even though less pronounced, differences between the first and second painting in the “Miro”-condition show that the effect is not due to the continuous presentation of the image in the Mondrian-condition.

4. CONCLUSIONS

Our results show that peripheral vision can be strongly modulated by knowledge. In particular, images that were unknown to the participant and only viewed peripherally (first painting) resulted in different perceptions when additional knowledge was acquired about the images (second painting). The large color effects in the unknown images cannot be explained by diminished color perception in the periphery as images were sufficiently close to the fovea where color vision is good. Abstract memory does not explain the appearance differences between the first and second paintings because several details were remembered but not perceived. Rather, we suggest that our results are due to vague percepts caused by crowding which are strongly susceptible to prior knowledge (see also, Sayim & Wagemans, 2013). Future experiments will show in how far the presentation of highly complex images modulates effects of crowding. We propose that the painting method is useful to explore the perception of complex stimuli, in particular to capture perceptually vague phenomena, as painting is more precise and efficient than, e.g., verbal descriptions when stimuli are complex. Finally, we suggest that artists who depict peripherally viewed scenes (e.g., Pepperell, 2012) for scientific or artistic purposes may benefit from the use of unknown images and gaze contingent presentation.

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