Study on perceptual properties of images presented by Saccade-based display — Asynchronous and depth perception

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Abstract

When we look at a one-dimensional light array while moving our eyes rapidly, the afterimage of the 1D light source will be spread on the retina so that we can recognize it as 2D image. Saccade-based display (SD), which uses this phenomenon and is composed of a 1D rapid blinking light-emitting diode (LED) array, can give the viewer the perception of a 2D image without a 2D screen. Perception with SD is remarkably different from ordinary display because the process of perception is different from when we look without eye movement. To make use of these perceptual properties for more effective presentation on SD, we performed experiments and found that some contents cause asynchronous and depth perception to the viewer.

1. Introduction

Ordinary 2D display shows an image on a 2D flat screen. To display a larger image, more energy and larger space are needed. Watanabe *et al.* [5] [4] proposed SD which can present 2D image with only a 1D light source using the perceptual property during rapid eye movement called saccade. SD can display a large image without large space because it consists of just a vertical LED array.

When we see a 1D flashing light source during saccade, the temporal patterns of the 1D light are spread on the retina. Then the information from the retina is reconstructed in the human vision system to be recognized as 2D image [3]. In other words, SD image can be displayed even in midair. This phenomenon has also been used in art [2]. SD flickers each one pixel column of the input image rapidly (around 2kHz). Although SD looks like a flickering light stick when we look at it without eye movement, we can perceive 2D image with saccade. To display accurately, saccade induction and saccade detection have been suggested [3]. Full-scale and full-color SD also has been developed [1]. Most research into SD is primarily concerned with the hardware aspect. In this paper, the aim is improvements of SD in the software side by investigating perceptual properties with various image contents.

Observing various images on SD, we found that each object in the same images is sometimes perceived at different timings. Moreover, some images causes multi-layered depth perception. For example, in Figure1(a), we recognize the fishes simultaneously on the same depth surface during one saccade, while in Figure 1(b) we perceive each fish at different timings on different depth layers. The former asynchronous perception may happen because the afterimage is spread temporally. It does not happen with traditional display because the image falls on the retina at once. The later depth perception may be induced because there is no screen with SD and the human vision system reconstructs the imaginary surface. In traditional displays, it does not happen because images are always on the screen. So, we can say that these are properties of SD. Some experiments were performed to reveal which distribution of objects on images gives us these perceptions.

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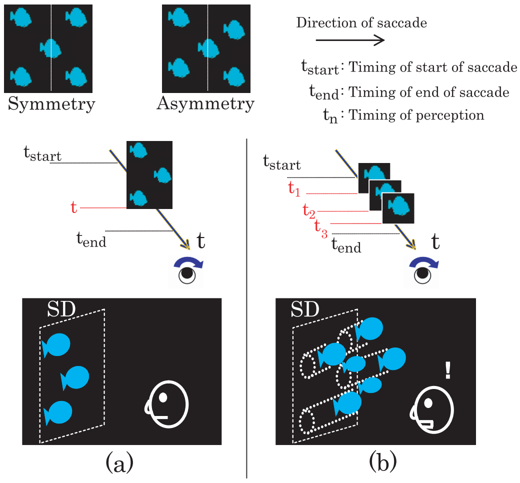

Figure 1. (a) Symmetric contents tend to cause simultaneous and flat perception. (b) Asymmetric contents tend to cause depth perception at different timing.

2. Experiment 1

In this experiment, we survey the perceptual properties for some contents with simple pattern.

2.1. Method

2.1.1 Subjects

Five female and eight male subjects (aged 21-26 years) with normal or corrected-to-normal visual acuity participated in this experiment.

2.1.2 Apparatus

The subject was seated 4.6m away from SD in a completely dark room. SD is made of 128 LEDs(Figure 2). It was controlled by an application developed in Visual C++ 6.0. The input image size was 128x128pixel. Because each pixel column of the image was displayed for 0.5ms, the necessary duration to show the whole image was 64ms. If the duration of saccade is less than 64ms or if the timing of saccade is off, we can not see the whole image. As we are concerned about more practical environment in this paper, the duration and the timing of saccade were not controlled. Only the visual angle was controlled: Two red LED markers were put on both sides of SD, 22.1 deg in visual angle apart. The subject was asked to move their eyes from one marker to another. The experiment was started after the subjects adapted to the dark environment.

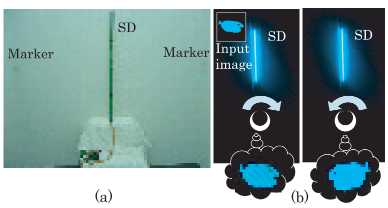

Figure 2. (a) SD. (b) SD images.

2.1.3 Stimuli

All of the visual stimuli were composed of a black background and four white circles. Each circle had a diameter of 1.5 deg and were distributed on the corner of rectangle Figure3 (a) 4.2degx4.2deg (b) 10.5degx4.2deg (c) 4.2degx10.5deg (d) 10.5degx10.5deg. To investigate the perception related to symmetry and asymmetry, we also used asymmetry stimuli whose left-upper circle is apart from others(Figure 3(d)-(h)).

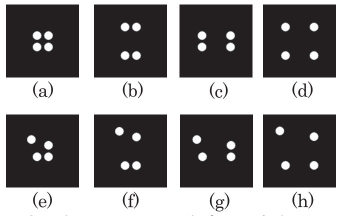

Figure 3. The contents. (left-to-right saccade)

2.1.4 Procedure

Each stimulus was displayed until the subjects were accustomed to seeing it on SD. The subjects were asked to sketch the image as they recognized it, and to answer asynchrony(AS), the number of group(GR), and the number of depth layers(DP). In the sketch task, although the direction of images changes depending on saccade direction, because the spatial position on the retina of visual information is reversed according to the saccade direction, they were allowed to sketch whichever images they perceived. AS was defined as 2 when they felt all circles appear at different timings; it defined as 0 when they felt it appear simultaneously. If the subject was unsure, they answered AS was 1. GR meant the number of the group whose circles are all perceived in the same depth layer. DP was the number of the depth layers they recognized. After they finished these four tasks, we displayed the next visual stimulus. It took around 3 minutes to finish all tasks on one visual stimulus.

2.2. Result

2.2.1 Result of AS

When the subjects drew only a part of the contents, we revised the AS to 2 because their sketch means they could not see the all of the contents at one time. Table 1 shows the average of AS. We show AS in order of the value in Figure 4. AS of asymmetric contents are larger than that of symmetric contents among the contents whose horizontal distance between circles is 4.2 deg. AS of the contents whose horizontal distance between circles is 10.5 deg are all high.

Table 1. Result of AS

No. in Figure2	a	b	c	d
AS	0	0.5	1.7	1.8
Figure	e	f	g	h
NO. in Figure2	1.1	0.8	1.8	1.6

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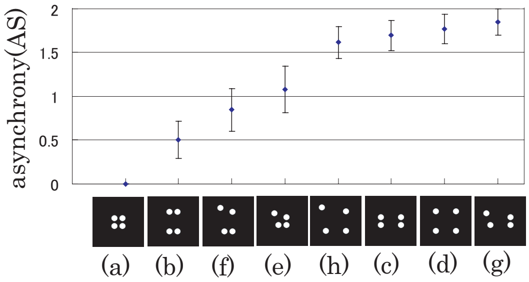

Figure 4. Average and SE of AS.

2.2.2 Result of GR

In Figure 3(c)(d)(g), and(h), more than seven subjects sketched a part of the contents or recognized so many circles at one time that they could not count GR. These two cases mean that the subjects could not recognize the whole image during one saccade for these contents. In AS, we used the results of these cases to analyze whether the subject can perceive the whole image easily or not according to the objects' patterns. We eliminated the GR result of these contents because now we want to know how each objects is perceived together. The average of GR in Figure 3(a)(b)(e), and(f) are shown in Table 2 because less than two subjects reported these cases in these contents. GR of asymmetric contents is larger than that of symmetric contents. This tendency that the objects tend to be recognized together when they are close to each other is the same as usual perception.

Table 2. Result of GR

No. in Figure2	a	b	c	d
GR	1.1	1.9	—	—
No. in Figure2	e	f	g	h
GR	2.0	2.5	—	—

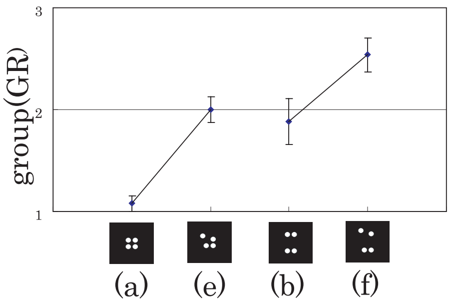

Figure 5. Average and SE of GR.

2.2.3 Result of DP

There are two cases when the subjects answered they could not count DP. One case is because too many circles on different depth were perceived at one time and it tends to happen especially in Figure 3(d) and (h). The other case is because the perceived image is different every saccade and it tends to happen in Figure 3(g). These two perceptions can not be combined because these are different perception. We eliminated this case and calculated the average of DP(Table 3). Most of the subjects reported that they perceived the circle that was separated from the others came to the front depth layer in the asymmetry contents. Table 2 and Table 3 shows that both GR and DP are larger in asymmetry contents than in symmetry contents.

Table 3. Result of DP

No. in Figure2	a	b	c	d
DP	1.0	1.1	1.0	1.2
No. in Figure2	e	f	g	h
DP	1.5	1.8	1.3	1.4

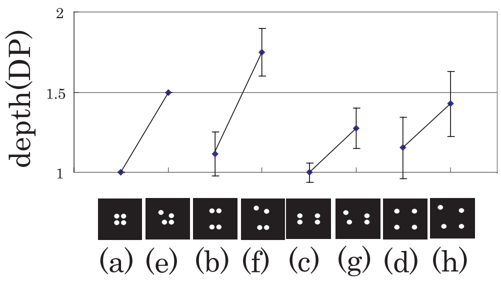

Figure 6. Average and SE of DP.

2.3. Discussion

We show the relationship between AS and DP in Figure 7. The left side contents(Figrue 3(a) and (b)) in Figure 7 give the viewers static images. The right side contents(Figure 3(c)(d)(g) and (h)) are difficult to recognize the whole image during one saccade. The asymmetric contents in the upper side give more depth perception than the symmetric contents in the lower side. Figure 3(f) and (e) give the viewers the depth perception at different timings during one saccade. We can say that the contents in this region are the most effective using the properties of SD.

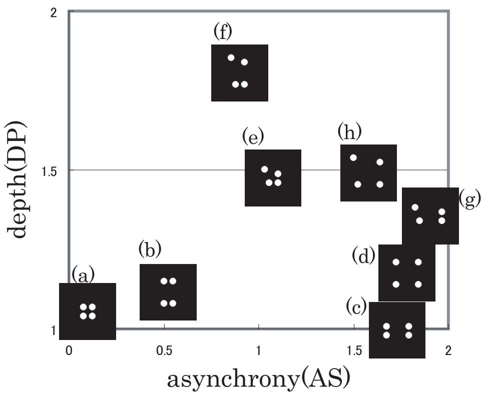

Figure 7. Relationship between AS and DP.

Asynchrony and depth perception do not happen in the case of usual 2D display. Then why these perceptions happen with SD? Let us compare the contents giving us static images (i.e. Figure 3(a) and (b)) and giving us dynamic images(i.e. Figure 3(f) and (e)). A big different point between these contents on 2D display is the distribution of circles. The distribution is uniform in symmetric contents and is nonuniform in asymmetric contents. This nonuniformity in 2D may induce temporal and spatial nonuniformity on SD because SD image is drawn on the retina time sequentially and do not have a screen in the real world.

3. Experiment 2

Experiment1 shows nonuniformity of location is the key of asynchronous and depth perception. To investigate it further, we made following experiment. The subjects were asked to answer just AS and DP. Other procedures and the apparatus were all the same as Experiment1.

3.1. Subjects

One female and five male subjects (aged 22-25 years) with normal or corrected-to-normal visual acuity participated in the experiment.

3.2. Stimuli

To find out whether only the nonuniformity of location causes these perception or other uniformity (i.e. shape, color, etc.) also induces it, we used the contents showed in Figure 8(b),(c). Moreover, to investigate further the effect of direction of the nonuniformity for perception, we used a vertical asymmetric image and a horizontal asymmetric image (Figure 8(d),(e)). The contents Figure 8(a) and (f) are same as Figure 3(a) and (e) in Experiment1.

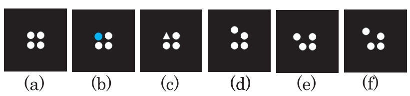

Figure 8. The contents (left-to-right saccade).

3.3. Result

The average and SE of AS and DP are shown in Figure 9 and Figure 10. All of the subjects reported that the white triangle and the blue circle in Figure 8(b) and (c) attracted their attention, but these stimuli caused neither asynchronous nor depth perception to them. In Figure 8(d), three of six subjects reported that one circle comes to the front layer. In Figure 8(e), two of six subjects answered the image seems to be stretched along the direction of saccade though, nobody reported depth perception. Two subjects reported the asynchronous perception in Figure 8(d) while five subjects in Figure 8(e) did.

Consequently, the direction of nonuniformity of distribution seems to be crucial for the depth perception. When the distribution is along saccade direction, the contents likely seem to be just stretched. In the case of vertical direction against saccade, the contents tend to come to the front layer.

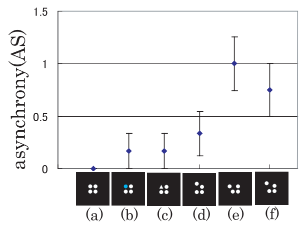

Figure 9. Average and SE of AS.

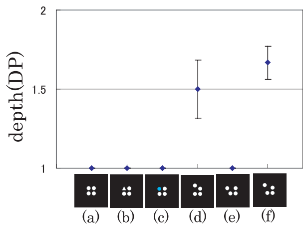

Figure 10. Average and SE of DP.

This result indicates that the direction of saccade has something to do with the perception on SD. Although color and shape seem not to be the key of asynchronous and depth perception from the result of Experiment2, more than two of six subjects reported that it is more difficult to recognize Figure 8(b)and(c) than Figure 8(a). We need to explore color and shape perception on SD.

Both the results of Experiment1 and Experiment2 show that the farther the distance between objects on the contents, the higher the value of AS become.

4. Conclusion

In this paper, we demonstrated that some contents can cause asynchronous and depth perception due to perceptual properties of SD. We found that the horizontal direction against saccade between two objects on contents is important for asynchronous perception and the vertical direction is crucial for depth perception. This result indicates that nonuniformity in 2D affects SD image perception as temporal and spatial nonuniformity.

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