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Perceiving static objects through moving apertures

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We investigated how the visual system recognizes static objects through moving apertures. In Experiment 1, observers searched for a bright static square among three dark squares. The search display consisting of ten frames and covered with dynamic grayscale noise with random or unidirectional motion and different numbers of apertures was presented for 133 ms. By measuring d', it was shown that detection was more sensitive in unidirectional than random noise, suggesting that temporal luminance summation played a minor role in detection. In Experiment 2, observers searched for a vertical bright bar among three vertical dark bars in the presence of dynamic noise with perpendicular, parallel or random to bar orientation. Detection was most sensitive in perpendicular noise motion, suggesting that successive visual transients visible through apertures, which are unrelated to noise motion, are critical in perceiving static objects through moving apertures.

Keywords: aperture viewing, visual transients, spatiotemporal integration

Purpose

The visual system can recover the appearance of moving objects from spatiotemporally fragmented image segments. For example, we often perceive the entire appearance of moving objects visible only through a thin aperture, even though the complete image of the object is not simultaneously presented. This kind of perception, called 'aperture viewing' (Morgan, Findley, & Watt, 1982), has been one of the interesting issues of study for vision researchers, because aperture viewing poses an important question about the way the visual system can recover the appearance of objects from incomplete visual inputs.

Meanwhile, identification generally improves provided that the observer pursues the moving object behind the aperture. In such viewing conditions, the spatiotemporally fragmented images successively stimulate different retinal positions. Some researchers have suggested the visual system utilizes retinally extended images stored in visible persistence. (Morgan et al., 1982) The spatiotemporal integration of neighboring fragmented images, called 'retinal painting', has been considered as the source of improved performance in aperture viewing when pursuit of moving objects with eye movements is allowed. Since the stimulus condition causing retinal painting is equivalent to that in which the observer's gaze remains fixed in a certain position while the aperture moves in front of static objects (hereinafter the latter is referred to as 'dynamic aperture viewing' in contraposition to 'typical aperture viewing' where the object, not the aperture, moves with restriction of eye movements), the nature of retinal painting can be effectively examined by assessing dynamic aperture viewing (Mateef, Popov, D., & Hohnsbein, 1993).

Although the underlying mechanism of typical aperture viewing has been extensively studied, our knowledge about the mechanism responsible for 'retinal painting' in dynamic aperture viewing seems limited. Specifically, it remains unclear how the visual system recovers the appearance of static objects through moving apertures, and no previous study has systematically examined the exact mechanism of dynamic aperture viewing.

The aim of this study was to examine what kind of visual information is necessary for dynamic aperture viewing. We found the significant role of spatiotemporal integration of visual transients in dynamic aperture viewing.

Experiment 1

Purpose

Experiment 1 was conducted to check whether local luminance cues are the critical factor in improving performances in dynamic aperture viewing. We utilized moving grayscale noise given some apertures Here we used multiple aperture stimuli as those used in Mateef et al. (1993). The observers' task was to search for a bright target among dark distracters. It was expected that the dynamic noise would mask the signal through the apertures when the number of apertures was small. It was also expected that the masking effect would be reduced when the number of apertures was high (Bowen & Wilson, 1994). In the latter condition, signals might be summed because dots with similar luminance values were frequently presented on the same retinal location. In the present experiment, we utilized two kinds of noise motion: one was uni-directed movement where the occluder containing apertures moved in a left or right direction, and the other was random replacement where the positions of the apertures as well as the luminance values on the occluder were randomly replaced. In both conditions, the luminance values for each dot were independently selected; therefore, luminance factors in both

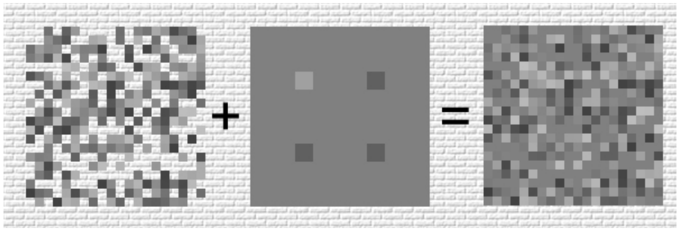

Figure 1. The method for making frames in the motion sequences in experiments 1 and 2. The left figure includes aperture dots (40 % of all dots) and the center figure is an example of a search display. By superimposing the left figure on the center figure, the right figure is obtained. The brick patterns in the background did not exist in the actual experimental stimuli.

noise conditions were equivalent to each other. Comparisons between these conditions enable us to dissociate the contribution of luminance cues from that of unique information in dynamic aperture viewing. More specifically, the critical factor in dynamic aperture viewing should be shown to be luminance summation over time, provided that there is no difference in performance between the two noise conditions. On the other hand, the visual function rather than luminance summation might work if there is a difference in performance.

Method

Observers. Four people including the author (TK) participated in the experiment. They had correct or corrected-to-normal visual acuities. Apart from the first author (TK), all observers were unaware of the purpose of the experiments.

Apparatus. A personal computer (Sony VAIO, Japan) controlled the presentation of stimuli and correction of data. Stimuli were presented on a gamma-corrected 19-inch CRT display (Nanao FlexScan T761, Japan) with a resolution of 1024 × 768 pixels and a refresh rate of 75 Hz.

Stimuli. A motion sequence consisting of 10 frames was presented to observers in each trial. Each frame, subtending 3.72 × 3.72 arc degrees, had 20 × 20 grayscale random-dots; each of which subtended 0.186 × 0.186 arc degrees. Each sequence contained a search display covered with dynamic noise. The dots in the dynamic noise were categorized into ‘noise dots’ occluding search displays and ‘aperture dots’ passing over them. The search display (the center figure in Figure 1) consisted of a bright square target (62.5 cd/m², subtending 0.372 × 0.372 arc degrees) and three dark square distracters (37.5 cd/m², subtending 0.372 × 0.372 arc degrees) in present trials or four dark square distracters in absent trials. The distance from the fixation cross (red vertical and horizontal lines) to the center of each search item was 1.05 arc degrees. Two types of dynamic noise were superimposed on the search display: (A) uni-directional noise: in the first frame (Frame 1) the number of aperture dots was randomly selected from 20, 40, 60, 80, and 100 % of 400 dots, and hence, that of noise dots was 80, 60, 40, 20, or 0 % of 400 dots, respectively. The positions of the aperture dots were randomly determined within a 20 × 20 matrix and other positions were assigned to noise dots. The luminance values of noise dots were randomly selected from 128 equally stepped luminance values ranging from 25 to 75 cd/m². The luminance values of aperture dots were selected from those at corresponding positions on the search display. In the following frames (Frames 2-10) apertures as well as noise dots moved in a left or right direction by steps of 0.186 arc degrees (one dot) so as to rule out the involvement of static cues in target detection. Mixing the two motion directions prevented motion aftereffects. Each frame was presented for 13.3 ms (1 vertical retrace interval) and thus one sequence was presented for 133 ms. The speed of moving dots was 14 degrees/sec. (B) Random noise condition: in every frame the positions of the aperture dots were randomly replaced within the matrix while the percentage of dots was one of the five amounts described in (A). The luminance values of noise dots were also randomly selected from the same ranges as in (A) and the luminance values of aperture dots were selected from those at corresponding positions on the search display. The presentation duration was the same as in (A).

Procedure. Observers sat at a distance of 80 cm from the CRT display and used a chin-head rest to stabilize their visual world. They were asked to judge whether or not the search display contained a bright square target among three dark square distracters. Each response was made by pressing assigned keys. A feed back tone (500 ms, 1000 Hz) was provided when the observers made an error response. One second after the response, the next trials began. Each observer received 400 trials (2 types of noise × 5 aperture percentages × 2 target presence/absence trials × 20 replications), which were divided into two sessions for each dynamic noise condition. A session consisted of four blocks and one block had 50 trials. Observers were allowed to take a break between blocks; each experiment took 20-30 minutes.

Results and Discussions

The results are shown in Figure 2 in which the abscissa indicates the aperture percentages on each frame and the ordinate indicates d’ as a measure of detection sensitivity. Two-way repeat measures ANOVA with the type of dynamic noise (2) × aperture probability (5) as factors showed the following. The main effect of types of noise was marginally significant ($F_{1, 3} = 9.417$, $p < .1$) while the main effect of aperture percentages was significant ($F_{4, 12} = 60.132$, $p < .001$). The interaction between the two factors was also significant ($F_{4, 12} = 4.430$, $p < .05$). Post-hoc analysis of the interaction showed that d’ was significantly different between the two types of dynamic noise when the aperture percentages were 40 and 60 % ($F_{1, 15} = 7.451$ and 22.677, $p < .05$, and .001, respectively).

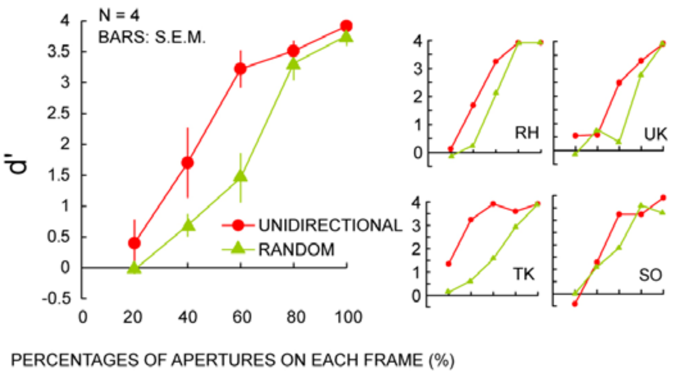

Figure 2. The results from experiment 1. The left graph shows the averaged d' across four observers as a function of the percentages of apertures in each frame. Vertical bars represent S.E.M. The four right graphs show the d' for each individual. Circles and triangles represent d' in the uni-directional motion and random noise conditions, respectively.

These results clearly showed that visual information other then luminance summation is involved in dynamic aperture viewing. As the number of apertures increased, the detection performance improved. This was consistent with the prediction by luminance summation. However, the performance was better with uni-directional noise than random noise when the percentages of apertures were 40 and 60%. Therefore, the difference between conditions cannot be explained by luminance summation.

The, what is the critical visual information in dynamic aperture viewing? In the uni-directional condition, the signal through the apertures was transient, and unrelated to noise motion. It was suggested that a neural code for transient signals is needed to construct visible persistence (Di Lollo, Hogben, & Dixon, 1994; Dixson & Di Lollo, 1994). The random noise condition also contained transient signals; however, since the noise as well as the apertures was transient, the saliency of the transient signals was likely to be reduced compared with in the uni-directional condition.

Experiment 2

Purpose

Experiment 2 was conducted to assess the involvement of saliency in spatiotemporal patterns of visual transients between noise and apertures during dynamic aperture viewing. We utilized two motion directions of noise, which were perpendicular and parallel to the orientation of the search items, respectively, and the random noise condition used in the first experiment. In the perpendicular motion condition, the visual transients are unrelated to noise motion and hence the saliency of the visual transients will be high (Figure 3a). On the other hand, in the parallel motion condition they are similar to the noise motion, and hence the salience will be low (Figure 3b). Performance in the perpendicular motion condition will therefore be better,

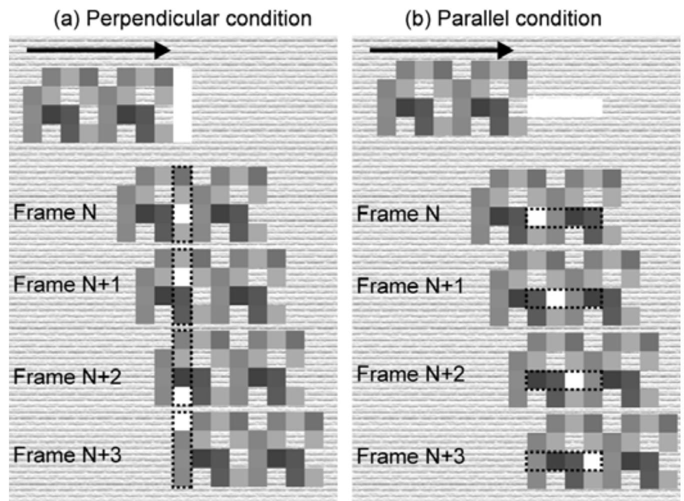

Figure 3. Schematic explanation of the stimuli used in experiment 2. (a) Perpendicular condition: the noise motion direction is perpendicular to the target, which results in the visual transients of the target being unrelated to noise motion. (b) Parallel condition: the noise direction is parallel to the target, which results in similar visual transients to the noise motion. In each panel, the white bar represents a target and the rectangle with a dotted outline represents the position of the occluded target. The white square in the dotted rectangle represents the visual transients of the target visible through apertures. The noise in this figure is given apertures in 25% of dots. The arrow indicates the motion direction of the noise with apertures.

provided that the saliency of the visual transients serves as a critical cue in dynamic aperture viewing. In the random noise condition, performance will be poor as observed in Experiment 1.

Method

Observers. Four people including the author (TK) participated in the experiment. They had correct or corrected-to-normal visual acuities. Apart from the first author (TK), none of the observers took part in the first experiment, and all were unaware of the purpose of the experiments.

Apparatus. The same apparatus as in the first experiment was also used.

Stimuli. The parameters (duration and number of frames, and size of dots) of each motion sequence were the same as those in Experiment 1 except for the following: the search display consisted of a vertical bright bar (62.5 cd/m², subtending 0.186 × 0.744 arc degrees) and three vertical dark bars (37.5 cd/m², subtending 0.186 × 0.744 arc degrees) in present trials or four vertical dark bars in absent trials. The distance from the fixation cross (red vertical and horizontal lines) to the center of each search item was 1.07 arc degrees. Three types of dynamic noise (perpendicular, parallel, and random motion) were utilized: (A) Perpendicular motion condition: in the first frame (Frame 1) the percentage (in number) of aperture dots was randomly selected from 10, 20, 30, 40, and 50 % of 400

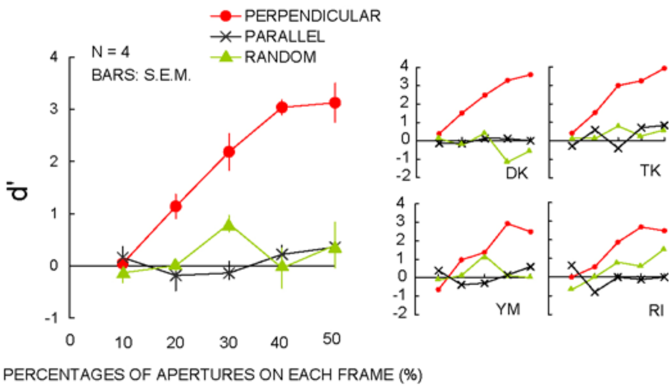

Figure 4. The results from experiment 2. The left graph shows the averaged d' across four observers as a function of the percentages of apertures in each frame. Vertical bars represent S.E.M. The four right graphs show the d' for each individual. Circles, crosses, and triangles represent d' in perpendicular, parallel motion and random noise conditions, respectively.

dots, thus the percentage of opaque dots was 90, 80, 70, 60, or 50 % of 400 dots, respectively. The positions of aperture dots were randomly determined within a 20 × 20 matrix and other positions were assigned to noise dots. The stimulus parameters (luminance ranges of noise dots and speed of motion) were the same as in the unidirectional dynamic noise condition in Experiment 1. The direction of noise motion was left or right, and therefore, was perpendicular to item orientation in the search display. To prevent the effect of motion aftereffects, these two motion directions were randomly interleaved among trials. (B) Parallel motion condition: the stimulus parameters in this condition were the same as in (A) except that the direction of movement of the dots was upwards or downwards; therefore, parallel to item orientation in the search display. (C) Random noise condition: the stimulus parameters were the same as in the random noise condition in Experiment 1 except for the following. In every frame the percentage of aperture dots was one of the five amounts described in (A).

Procedure. The procedure was the same as in the first experiment except for the following. Each observer received 600 trials (3 types of noise × 5 aperture percentages × 2 target presence/absence trials × 20 replications), which were divided into 3 sessions for each dynamic noise condition. A session consisted of four blocks and one block had 50 trials. Observers were allowed to take a break between blocks. The experiment took 40 minutes.

Results and Discussions

The results are shown in Figure 4 in which the abscissa indicates the aperture percentages on each frame and the ordinate indicates d' as a measure of detection sensitivity. Two-way repeat measures ANOVA with the type of dynamic noise (3) × aperture probability (5) as factors showed the following. The main effect of the types of dynamic noise was significant ($F_{2,6} = 31.231$, $p < .0001$). Multiple comparison tests (Ryan's method) showed that the d' in the perpendicular motion condition was significantly different from that in the other two conditions ($p < .001$). The main effect of aperture percentages was also significant ($F_{4,12} = 30.778$, $p < .0001$) as was the interaction between the two factors ($F_{8,24} = 9.879$, $p < .0001$).

These results support the prediction that visual transients unrelated to noise motion play a critical role in dynamic aperture viewing. Of all conditions, performance was best with the perpendicular condition. Performance in the parallel motion condition was not better than that in the random condition indicating that the mere presence of noise motion cannot improve performance. Collectively, these results suggest that visual transients unrelated to noise motion are the key feature in dynamic aperture viewing.

Conclusion

This study examined how the visual system recovers the luminance of static objects through moving apertures in the presence of dynamic luminance noise (dynamic aperture viewing). In the first experiment, we showed that luminance summation was only a marginal factor in dynamic aperture viewing. In the second experiment, we found that recovery of the appearance of static objects was more successfully conducted when the apertures moved perpendicular to the search items rather than parallel to them. These results indicate that spatiotemporal integration of salient visual transients plays a critical role in dynamic aperture viewing.

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