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VISUAL STREAM SEGREGATION AND PERCEPTUAL GROUPING BY SHAPE SIMILARITY

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Two experiments were performed to examine whether the perceptual grouping by shape similarity affected visual stream segregation (VISS), in which four lights appear to be a set of two apparent motion (streams) when flashed at a moderately fast rate. Sixteen undergraduates found the upper limits of the stimulus-onset asynchrony (SOA) for producing VISS under various conditions of arrangement of shape in four vertical positions. The experiments showed that the SOA was longer where the grouping by shape similarity was compatible with the original grouping of VISS than where there was no grouping due to shape. They also showed that the SOA was shorter where the grouping by shape was not compatible than where there was no grouping due to shape. The results indicate that, in addition to the flashing rate of the lights, the perceptual grouping is another important factor to produce VISS. They also show that VISS is a type of apparent motion affected by the perceptual organization among stimuli in the display.

Key words: visual apparent motion, visual stream segregation, perceptual grouping, shape

Visual stream segregation (VISS) is a type of apparent motion that Bregman and Achim (1973) introduced. Four lights, a, b, c, and d, which are located in a vertical row in that order, flashing at a moderately high speed in order, a, c, b, and d, appear to be a set of two apparent motion (streams); one between a and b, and the other, c and d. Bregman and Achim (1973) demonstrated experimentally that the four lights should be alternated at a moderately fast rate for producing VISS. Is a fast flashing rate enough to produce VISS? In their spatial arrangement of VISS, the four lights were always located to make perceptual grouping into two groups, one group of a and b, and the other, c and d, based on the proximity law of Gestalt. The fact suggests that the perceptual grouping, or perceptual organization, of the four lights is a factor in producing VISS.

Watanabe (1992) reported that perceptual grouping by intensity similarity affected VISS. He (1992) measured the upper limits of the interstimulus-interval (ISI) for producing VISS with the duration constant, varying the arrangement of intensity among the four lights which were originally grouped into two groups (a and b; c and d) by the proximity law. The arrangement of intensity resulted in an additional grouping by intensity similarity of the four lights with the original grouping of VISS. The ISI was larger when the additional grouping was compatible (C) with

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the original grouping than when the additional grouping was incompatible (IC). According to Gestalt law, similarity is one of the factors to facilitate grouping (Koffka, 1935; Wertheimer, 1958): Elements with similar qualities will constitute a group apart from those with dissimilar qualities. The compatibility of the grouping by intensity similarity with the original grouping of VISS, allowed the subject to perceive VISS in the C condition at the longer ISI, namely, at a slower rate, than in the IC condition.

Now there are the following issues to be resolved. First, does the perceptual grouping by similarity based on the shape have the same effect as that based on the intensity which Watanabe (1992) demonstrated? Second, how does the perceptual grouping affect VISS? The present study, therefore, examines whether and how the perceptual grouping by shape similarity affects VISS, using a similar method to Watanabe's (1992).

The four lights are originally located to make a grouping of VISS (a and b; c and d) by the proximity law throughout the experiments. Various perceptual groupings by shape similarity were added to the four lights with the original grouping of VISS. The measured index was the upper thresholds of the stimulus-onset asynchrony (SOA) for producing VISS, the necessary SOA for a change to occur between a stream (non-VISS) and two streams (VISS). The subject varied the SOA to produce VISS with the durations of the lights equally constant.

The rationale for the measurement was as follows. The additional perceptual grouping by shape, when compatible with the original grouping of VISS, facilitates VISS and should allow the subjects to perceive VISS at longer SOA, namely at a slower rate, than when not. Conversely, the additional grouping, when incompatible with the original grouping, inhibits VISS and should allow the subjects to perceive VISS at shorter SOA, namely at a faster rate, than when not. On the basis of the results, effects of perceptual grouping by shape similarity on VISS are discussed.

Experiment 1

The present experiment examined whether the grouping by shape similarity affected VISS. The upper limits of SOA for producing VISS were measured following the method of adjustment, where either grouping or shape was varied in two ways, respectively.

Method

Subjects: The subjects were 10 male undergraduates from Kinki University in Kyushu. All had normal or corrected-to-normal vision and were naive as to the experiment of apparent motion.

Apparatus: A set of four electroluminescent (EL) panels were flashed successively, using a power source for EL panels. The time schedules of flashing were controlled by a five-channel digital timer, a one-channel remote-controlled timer, and a time-controller. Four panels were flashed with the durations equally constant, the SOAs between them equal, and the intercycle interval (ICI) constant. The SOAs were adjustable by using two buttons of a switch on the remote-controlled timer. The time adjusted by the subject was displayed digitally in milliseconds to the experimenter.

Stimulus display: The stimulus display consisted of a set of four EL panels, a, b, c, and d, which were arranged in a vertical line as shown in Fig. 1. The display was determined by two variables. The first

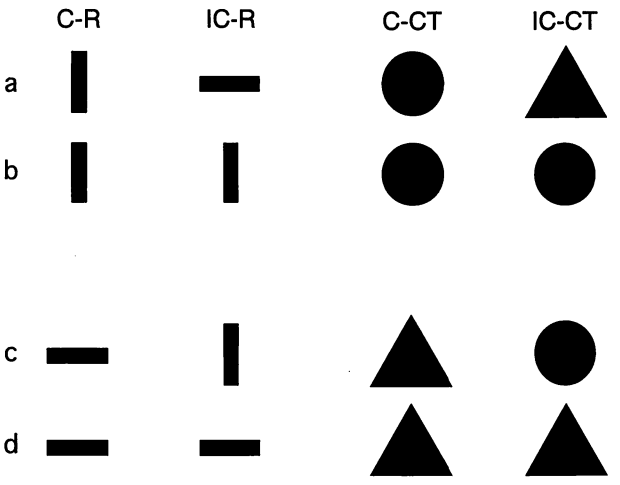

Fig. 1. Illustration of stimulus displays used in Experiment 1. Rows: locations of four lights, a, b, c, and d, in a vertical line. Columns: combined conditions of grouping (C, IC) and shape (R, CT).

variable was grouping; compatible (C), and incompatible (IC). In the C condition, the a and b pair, and the c and d pair were equal in shape within a pair, whereas the two pairs were different in shape between the pairs. In the IC condition, the pair of a and b and that of c and d were different in shape within a pair, whereas b and c were equal in shape. The second variable was shape; rectangles (R) and circle-triangle (CT). In the R condition, the shape was either a rectangle or its shape was rotated 90 degrees in the picture plane. In the CT condition, the shape was either a circle or a triangle. A combination of the variables resulted in four conditions; C-R, IC-R, C-CT, and IC-CT.

The intercentral spatial distances were 1.15° of visual angle between a and b, 1.15° between c and d, and 2.3° between b and c. Each of the panels, covered with a black flock paper with an aperture, resulted in a solid shape of either rectangle, circle, or triangle. The rectangle was $0.19° \times 0.76°$ in visual angle. The circle was 0.76° of visual angle in diameter. The triangle was a regular triangle with 1.03° of visual angle per side. The circle and triangle were almost equal in area. In addition, another visual display, which consisted of four squares of 0.57° of visual angle per side, was prepared for practice. All the panels were about 50 cd/m^2 in luminance. A green light-emitting diode was located in the middle between b and c as a fixation point. It was 0.11° of visual angle in diameter and about 3 cd/m^2 in luminance.

Procedure: A set of four panels was flashed in order of a, c, b, and d, repeatedly. The duration of each panel flash was always 200 ms, while the ICI was always 500 ms from the offset of d to the onset of a. The subject sat at a table with his head located on a chin-rest and observed binocularly the stimulus display 150 cm distant from him. He judged the appearance of the display, while staring at the fixation point.

The experiment was performed in two sessions. The first session consisted of discrimination, observation, and adjustment tasks. The second session consisted of observation and adjustment tasks. In the discrimination task, a sequence of flashings of a set of panels was displayed to the subject, using the stimulus display for practice. He was required to judge whether the apparent sequence of flashings was similar to VISS or not under some SOAs between 70 ms and 200 ms. The task was intended to ascertain whether or not he learned to differentiate between VISS (two streams) and apparent motion in the order of presentation (one stream). The task finished when the subject reported of VISS at shorter SOAs and of apparent motion in the order of presentation at longer SOAs.

In the observation task, the sequence of flashings was displayed, while the SOA was varied continuously from 70 ms to 250 ms or from 250 ms to 70 ms by the experimenter. The subject observed the change of the appearance of the flashings caused by a change of the SOA for each experimental condition.

In the adjustment task, the subject found a transition point of SOA at which a change occurred between VISS and apparent motion in the presented order. The transition point, considered a threshold

of SOA, was the upper limit of SOA for producing VISS. A trial consisted of an ascending series and a descending series. In the ascending series, the subject lengthened the SOA starting from 70 ms until VISS ceased to appear, using the buttons of a switch on a remote-controlled timer. In the descending series, he shortened the SOA starting from 250 ms until VISS began to appear. The upper limit of SOA data resulted from the averaged SOA across ascending and descending series for each trial.

The adjustment task consisted of six blocks with three blocks for each session. The subject received a trial for each experimental condition in random order in a block. The first block was for practice trials, and the other five blocks were for test trials. A two-minute rest was given between blocks. The order effect was counterbalanced between blocks and across subjects. Ten minutes was given for adaptation to the dark before each session. The subject was tested individually in a darkened room.

Results

Mean upper limits of SOA were used as data after being averaged for each subject through five test trials in each condition. Fig. 2 shows the mean SOAs averaged for 10 subjects in each condition. As is seen in Fig. 2, the SOA for the C condition is longer than that for the IC condition. A difference in the SOA between the C and IC conditions is larger for the R condition than that for the CT condition.

The SOA data were examined by using a 2×2 (grouping $\times$ shape) analysis of variance. A significant main effect of grouping was obtained ($F(1, 27)=24.03$, $p<.01$), as well as a significant interaction effect of grouping with shape ($F(1, 27)=7.73$, $p<.01$). The main effect of shape was not significant ($F(1, 27)=0.73$, $p>.05$). The t test was performed on the data between two conditions of grouping under each shape condition. The SOA for the C condition was significantly longer than that for the IC condition under either the R or CT condition, respectively ($t(9)=6.12$, $p<.01$; $t(9)=4.32$, $p<.01$). The t test was performed on the data between the two conditions of shape under each grouping condition. Under the C condition, the SOA for the R condition was significantly longer than that for the CT

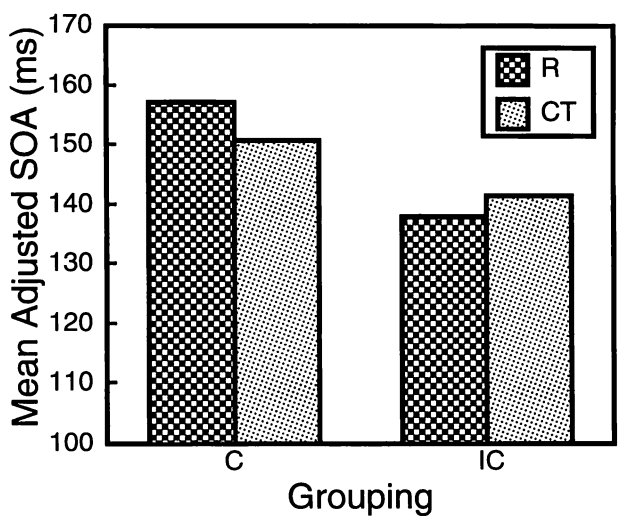

Fig. 2. Mean adjusted upper limits of SOA for perceiving VISS under each condition of shape as a function of grouping (Experiment 1).

condition ($t(9)=3.90$, $p<.01$). Under the IC condition, no significance was found between the R and CT conditions ($t(9)=1.48$, $p>.05$). Further, the difference data in the SOA were obtained between the C and IC conditions for each condition of shape; R and CT. The differences were 19 and 9 ms, respectively, for the R and CT conditions. The t test showed that there was a significant difference between the R and CT conditions ($t(9)=4.04$, $p<.01$).

Experiment 2

The present experiment was performed to explain how the grouping by shape affected VISS. Two rectangles differing in orientation were used as shape because the clearer effect of grouping was obtained for the R condition than for the CT condition in the first experiment. The upper limits of SOA were measured in the same way as in the first experiment.

Method

Subjects: The subjects were 10 male undergraduates from Kinki University in Kyushu. All had normal or corrected-to-normal vision. Four of them were naive as to the experiment of apparent motion, and the rest had participated in the first experiment.

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

Stimulus display: The stimulus display consisted of a set of four EL panels arranged in a vertical line as shown in Fig. 3. The arrangement of the same rectangles as in the first experiment resulted in five conditions. The compatible (C) condition was the same as the C-R condition in the first experiment. In the all-vertical (AV) condition, all the four rectangles were oriented in the vertical direction. In the all-horizontal (AH) condition, all the rectangles were oriented in the horizontal direction. In the horizontal-vertical (HV) condition, the rectangles were oriented alternately in the horizontal and vertical direction. The incompatible (IC) condition was the same as the IC-R condition in the first experiment.

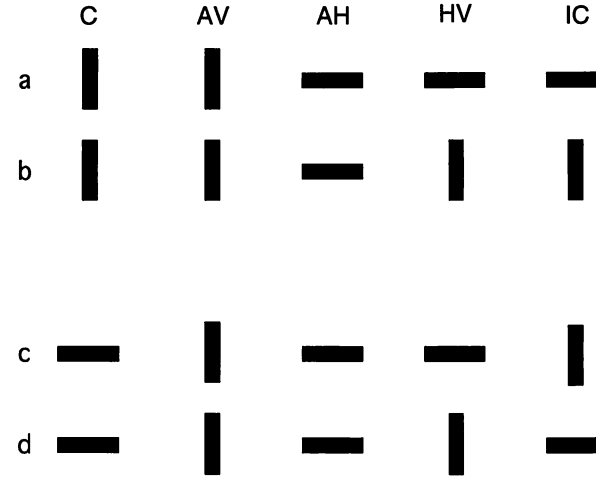

Fig. 3. Illustration of stimulus displays used in Experiment 2. Rows: locations of four lights, a, b, c, and d, in a vertical line. Columns: conditions, C, AV, AH, HV, and IC.

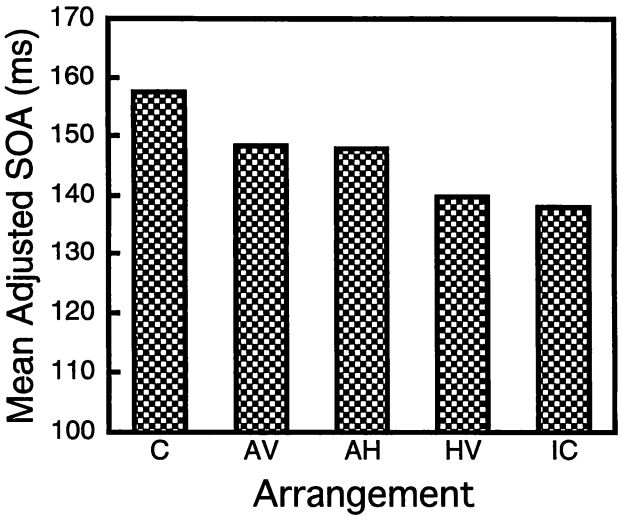

Fig. 4. Mean adjusted upper limits of SOA for perceiving VISS under each condition of arrangement (Experiment 2).

The luminance and the size of the rectangles were the same as in the first experiment. The spatial distances among a, b, c, and d were the very same as in the first experiment. The fixation point was located in the same way as in the first experiment.

Procedure: The set of four panels was flashed in the same way as in the first experiment. The experiment was performed in two sessions in the same way as in the first experiment. The adjustment task consisted of six blocks in two sessions. The subject was required to complete a trial for each experimental condition in a block in random order. The first block was practice trials, and the other five blocks were test trials.

The procedure was the same as in the first experiment except for the changes above.

Results

Mean upper limits of SOA were used as data after being averaged for each subject through the five test trials in each condition. Fig. 4 shows the mean SOAs averaged for 10 subjects in each condition. As is seen in Fig. 4, the SOA for the C condition is the longest, and the SOAs for the HV and IC conditions are the shortest of all the conditions. The SOAs for the AV and AH conditions are shorter than the SOA for the C condition and longer than the SOAs for the HV and IC conditions. No difference is noticeable between AV and AH and between HV and IC.

The SOA data were analyzed by using a one-way analysis of variance. The main effect of arrangement was significant ($F(4, 36)=12.22$, $p<.01$). The lower test was performed on the data by using Fisher's least significant difference test. A significant difference was obtained between each pair of the conditions except a pair of the AV and AH conditions and that of the HV and IC conditions ($LSD=6.46$, $p<.05$).

Discussion

The purpose of the present study is to examine whether and how the perceptual grouping by shape similarity affects VISS. The four lights were originally located to make perceptual grouping into two groups, one group of a and b, and the other, c and d, based on the proximity law of Gestalt. Varied were the additional grouping based on shape similarity applied to the four lights with the original grouping of VISS. The measured index was the upper limits of SOA to produce VISS.

Experiment 1 showed that the SOA for the C condition was longer than that for the IC condition irrespective of the shape; R (rectangles varying in orientation) or CT (circle or triangle). The additional grouping by shape is compatible with the original grouping of VISS in the C condition, while incompatible in the IC condition. The results support that the grouping by shape similarity affects VISS in the same way as the grouping by intensity similarity. Since a clearer effect of grouping was obtained for the R condition than for the CT condition, to explore how the grouping by shape affects VISS the rectangles were used as shape for Experiment 2.

Experiment 2 showed that the SOA was longer for the C condition than for the AV and AH conditions. There was no difference between the AV and AH conditions. According to the similarity law of Gestalt, elements with similar quality will constitute a group apart from those with dissimilar quality (Koffka, 1935; Wertheimer, 1958). In both AV and AH conditions, the shape does not add any effect to the original grouping because all the four lights are the same in shape. However, in the C condition, the similarity of shape strengthens the original grouping of VISS to produce VISS at the longer SOA, namely at a slower rate, than in the AV and AH conditions.

A clearer answer to how the grouping by similarity affects VISS is brought by examining the differences in SOA among the AV, AH, HV, and IC conditions. The SOA was shorter for the HV and IC conditions than for the AV and AH conditions. In both HV and IC conditions, the similarity of shape weakens the original grouping to produce at the shorter SOA, namely at faster rate, than in the AV and AH conditions. This is because the elements (a and b; c and d) within each stream of VISS are different in shape under both conditions. In addition to the difference within each stream, the near elements (b and c) are the same across streams of VISS in the IC condition. For this reason, the similarity law maintains that the grouping by similarity weakens the original grouping further to produce VISS at shorter SOA in the IC condition than in the HV condition. However, the difference in the arrangement of the stimuli brought no difference in the SOA between the conditions.

Based on the results we obtained through the experiments, the perceptual grouping by similarity affects VISS in the following way. To produce VISS it is important that the elements are similar within each stream of VISS. VISS is facilitated further if the elements are dissimilar between the streams in addition to the similarity within the stream. VISS is inhibited only if the elements are dissimilar within each stream of VISS. VISS is never facilitated further even if the near

elements are similar across the streams in addition to the dissimilarity within the stream, which, according to the similarity law, should contribute to weaken the grouping of VISS.

Bregman and Achim (1973) demonstrated that a flashing rate of four lights is an important factor to produce VISS, never referring to the spatial configuration of the lights to produce VISS though they always located the lights to make a perceptual grouping into two groups (a and b; c and d) based on the proximility law of Gestalt. Our results suggest that the perceptual grouping of the lights or the perceptual organization is also an important factor to produce VISS.

VISS is a type of apparent motion, about which little is known. What we have known is that VISS follows Korte' law related to the spatial distance between lights and to their intensity (Ohmura, 1982, 1984; Watanabe, 1981, 1992, 1993). The present study has added a new knowledge that VISS is affected by the perceptual organization among the stimuli like the other types of apparent motion (Anstis, 1978; Ramachandran & Anstis, 1986; Ternus, 1950; Watanabe & Kubo, 2000).

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