

Effects of size and luminance of stimulus on visual stream segregation

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To investigate the effects of stimulus size and luminance on visual stream segregation (VISS), I measured the upper limits and the optimal values of the interstimulus interval (ISI) for producing VISS. Although the effect of luminance was small when the stimulus size is large, the results were generally consistent with Korte's second law saying that the ISI decreases as the stimulus intensity increases to produce optimal beta movement. This is favorable to Ohmura's (1982) notion that VISS is functionally equivalent to beta movement because VISS can be regarded as a compound phenomenon consisting of two beta movements. These results show that both of the stimulus size and luminance function as intensity for producing VISS. The process of producing VISS was examined based on Ullman's (1979) theory of motion correspondence.

Key words: beta movements, visual stream segregation, stimulus size, luminance, Korte's law, interstimulus interval, motion correspondence, affinity.

Four lights are located in a vertical row, and named A, B, C, and D, in order from top to bottom. The spatial distance between A and B is equal to that between C and D. The distance between B and C is longer than that between A and B and that between C and D. Four lights are flashed successively in the order, A, C, B, and D. When they are flashed at a slow rate, a light is seen moving back and forth among the positions A, C, B, and D, in that order. When they are flashed at a faster rate, two lights are seen moving, one between the positions of A and B, and the other between those of C and D. Bregman and Achim (1973) named the phenomenon "visual stream segregation (VISS)."

VISS was introduced as a visual analogy of "primary auditory stream segregation (PASS)." PASS is a phenomenon in which a fast sequence of high and low tones splits into two separate perceptual streams, one consisting of the high tones and the other of the low tones (Bregman & Campbell, 1971; Dannenbring & Bregman, 1976). PASS has been studied extensively by some psychologists. However, VISS has not been examined extensively. There is very little experimental

data to explain variables that affect VISS and to construct the mechanism by which VISS was produced. The present study was designed to provide some additional experimental data to explain VISS and construct the mechanism.

Bregman and Achim (1973) thought of VISS as a kind of beta movement and obtained the results that VISS followed Korte's third law (Korte, 1915). This law states that the interstimulus interval (ISI) between the stimuli increases with the spatial distance between them to produce optimal beta movement. The results were explained by Bregman and Achim (1973) as follows. The fast rate (short ISI with duration constant) favors beta movements between short distances, those between A and B and between C and D and thus produces VISS. The slow rate (long ISI) favors beta movements between long distances in the presented order, and thus does not produce VISS. Watanabe (1981) also obtained the results that were consistent with the law. He found that the ISI for producing VISS increased with the shortest spatial distance between the two beta movements, namely, the distance between B and C

in the VISS configuration as mentioned above.

Ohmura (1982) obtained the results that VISS followed Korte's fourth law. The law states that the ISI between the stimuli decreases with an increase in the duration of the stimulus to produce optimal beta movement. She also obtained the results that VISS followed Kahneman's ISI law (Kahneman & Wolman, 1970) which applies to beta movement between two stimuli. The law states that the ISI between two stimuli is constantly zero to produce optimal beta movement when the duration of the stimulus was over 100 ms. On the basis of the results, she concluded that VISS was functionally equivalent to beta movement, and that it was, in form, regarded as a compound phenomenon consisting of two beta movements.

If Ohmura (1982) had the right notion of VISS, Korte's laws concerning the intensity of the stimulus should also apply to VISS. Ohmura (1986) examined the effect of the intensity (luminance) of the stimulus on VISS. Nevertheless, she did not obtain any results that indicated the effect of the intensity. On the contrary, Watanabe (1992) obtained results that the ISI decreased as the intensity (luminance) of the stimulus increased to produce VISS. The results were consistent with Korte's second law. The law states that the ISI decreases as the intensity of the stimulus increases to produce optimal beta movement.

The different experimental methods may explain the different results. Ohmura (1986) asked the subjects to rate the appearance of VISS on the visual display for its goodness in each condition of the stimulus-onset asynchrony (SOA), that is the time from the onset of the stimulus to the onset of the next stimulus. What was compared was the peak value of the SOA, namely, the value of SOA to obtain optimal VISS. This was because she attached importance to the goodness of VISS. On the other hand, Watanabe (1992) examined the upper limit of the ISI that was directly adjusted by the subject to produce

VISS. This was because he attached importance to a differentiation between a beta movement in the order of presentation and two simultaneous beta movements (VISS), following Bregman and Achim (1973). The difference between SOA and ISI is not important here because SOA is translated easily into ISI.

According to Graham (1951), Korte (1915) used the term intensity to refer to not only the luminance of the stimulus but the size. Does the size of the stimulus affect VISS in the same way as the luminance? Do the luminance and the size of the stimulus interact with each other to produce VISS? Why were different results obtained between Ohmura (1986) and Watanabe (1992)?

The present study examines the effects of size and luminance of the stimulus on VISS, using the same method as Watanabe (1992) and a method similar to that of Ohmura (1986). On the basis of the results, the effect of intensity on VISS is discussed.

Experiment 1

This experiment examined the effect of the size of the stimulus on VISS. The upper limits of ISI for producing VISS were measured following the method of adjustment, where the size of the stimulus was varied in three levels.

Method

Subjects. The subjects were eight (two female and six male) undergraduates from Kinki University in Kyushu. All had normal or corrected-to-normal vision, and were naive to the experiment of beta movement.

Apparatus. A set of four electroluminescent (EL) panels was flashed successively, using a power source for EL panels. The time schedules of flashing were controlled by a two-channel digital timer, a one-channel remote-controlled timer, and a time-controller. Four panels were flashed with the durations equally constant, the ISIs between them

equal, and the intercycle interval (ICI) constant. The ISIs 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 rectangles of EL panels, A, B, C, and D, which were arranged in a vertical row as shown in Figure 1. The intercentral spatial distances were 1.15° of visual angle between A and B, between C and D, and 2.3° between B and C. Three sizes of panels were prepared. The widths of the panels were 0.02° , 0.23° , and 2.3° of visual angle, while keeping the height of the panels constantly 0.23° of visual angle. The panels were about 150 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 0.05° of visual angle in diameter and 3 cd/m^2 in luminance.

Procedure. A set of four panels, which were stimuli, was flashed in the order A, C, B, and D, repeatedly. The duration was always 50 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

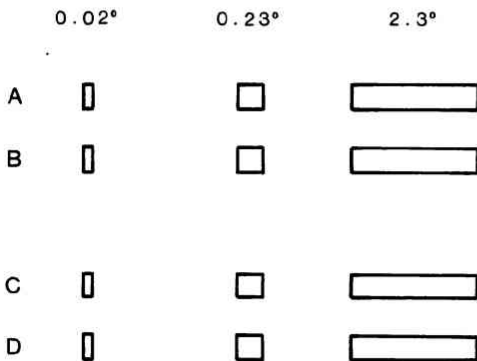


Figure 1. Stimulus display used in Experiment 1. The widths of the stimuli were changed (0.02° , 0.23° and 2.3° of visual angle) with their heights constant (0.23°).

the fixation point. The session consisted of 3 tasks: training, observation, and adjustment.

In the training task, a sequence of flashings of the set of panels was displayed to the subject. The subject was trained to understand a differentiation between VISS and beta movement in the order of presentation. He was required to judge whether the apparent sequence of flashings is similar to VISS or not under some ISIs between 30 ms and 300 ms. After a few trials, when the subject constantly reported perceiving VISS in shorter ISI and not in longer ISI, the task ended. The stimulus display in the 0.23° condition was used for this task.

In the observation task, the sequence of flashings was displayed, while the ISI was varied continuously from 30 ms to 300 ms or from 300 ms to 30 ms by the experimenter. The subject observed the change of the appearance of the flashings caused by a change of the ISI under each condition of size.

In the adjustment task, the subject was asked to find the transition point of ISI at which a change occurred between VISS and beta movement in the order of presentation. A trial consisted of an ascending series and a descending series. In the ascending series, the subject lengthened the ISI starting from 30 ms until VISS ceased to appear, using the buttons of a switch on the remote-controlled timer. In the descending series, he shortened the ISI starting from 300 ms until VISS began to appear. The upper limit of ISI for producing VISS was the average of the ascending series and descending series. The transition point was considered as a threshold.

The adjustment task consisted of six blocks of three trials with a trial for each size condition per block in random order. A two-minute rest was given between blocks. The order effect was counterbalanced between blocks and across subjects. Five minutes were given for dark adaptation before the experiment. The subject was tested individually in a dark room.

Results

The first block was practice trials and the other were test trials. Mean upper limits of ISI were used as data after being averaged for each subject through five test trials in each condition. Figure 2 shows the mean ISIs averaged for eight subjects in each size condition. As is seen in Figure 2, the ISI decreases as the size of the stimulus increases. The ISI data were examined by a one-way analysis of variance. The main effect of size was significant ($F(2, 14)=10.05, p<.005$). The lower test was performed on the data by using the least significant difference. A significant difference was obtained between 0.02° and 0.23° and between 0.23° and 2.3° ($LSD=21.36, p<.05$). A significant difference was also obtained between 0.02° and 2.3° ($LSD=29.64, p<.01$).

Experiment 2

This experiment examined the effects of the size and the luminance of the stimulus and their interacting effect on VISS. The size and luminance of the stimulus were both varied in two levels. The upper limits of ISI for perceiving VISS were measured following the same method as in the first experiment under each condition of size and luminance.

Method

Subjects. The subjects were eight (two female and six male) undergraduates from

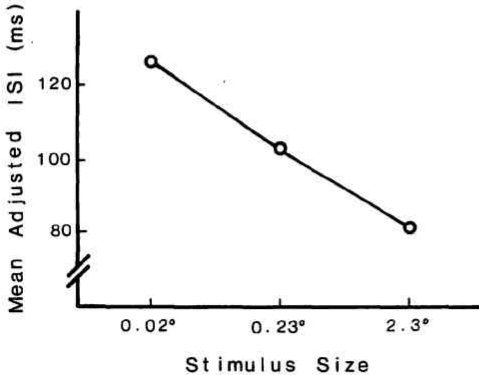


Figure 2. Mean adjusted upper limits of ISI for perceiving VISS as a function of stimulus size (Experiment 1).

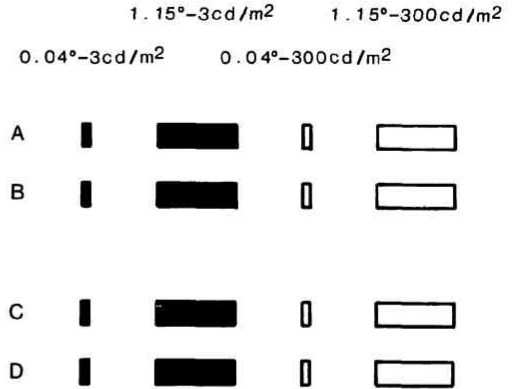


Figure 3. Stimulus displays used in Experiments 2 and 3. The widths of the stimuli were changed (0.04° , and 1.15°) with their heights constant (0.23°). The luminance levels were 3 cd/m^2 (solid rectangle) and 300 cd/m^2 (open rectangle).

Kinki University in Kyushu. All had normal or corrected-to-normal vision. Two of them were naive as to the experiment of beta movement, and the rest had served as subjects in the first experiment.

Apparatus. The apparatus were the same as used in the first experiment.

Stimulus display. A set of four rectangles of EL panels was used as a stimulus display. It was similar to that used in the first experiment. Two sizes of panels were prepared. The widths of the panels were 0.04° and 1.15° of visual angle, while keeping the height of the panels constantly 0.23° of visual angle. Two levels of luminance were prepared: 3 cd/m^2 and 300 cd/m^2 . The luminance of 3 cd/m^2 was produced by mounting a Kodak Wratten neutral density gelatin filter No. 96 (1% of transmissivity) on the panel of 300 cd/m^2 in luminance. Four conditions resulted from a combination of variables of size and luminance as shown in Figure 3. A fixation point was located in the same way as in the first experiment. It was the same light-emitting diode as in the first experiment, but 0.3 cd/m^2 in luminance.

Procedure. The set of four panels, which were stimuli, was flashed in the same way as in the first experiment. The subject was tested

in a set of 3 tasks: training, observation, and adjustment. The stimulus display in the 0.04° -300 cd/m^2 condition was used for the training task. The adjustment task consisted of six blocks of four trials, a trial for each of the four conditions in random order.

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

Results

The first block was practice trials and the other were test trials. Mean upper limits of ISI were used as data after being averaged for each subject through the five test trials in each condition. Figure 4 shows the mean ISIs averaged for eight subjects in each condition of luminance as a function of the size of the stimulus. As is seen in Figure 4, the ISI decreases with an increase in the size. The ISI decreases more slowly in 300 cd/m^2 condition than in 3 cd/m^2 . The ISI is shorter in 300 cd/m^2 than in 3 cd/m^2 under the 0.04° condition. The ISI in 300 cd/m^2 is almost equal to that in 3 cd/m^2 under the 1.15° condition.

The ISI data were examined by using a 2×2 (luminance \times size) analysis of variance. A significant main effect of size was obtained ($F(1, 7)=72.6, p<.01$), as well as a significant interaction effect of luminance with size ($F(1, 7)=7.37, p<.05$). The t tests were performed

between two conditions of size under each luminance condition. The ISI was significantly shorter in the 1.15° condition than in the 0.04° condition under either 3 cd/m^2 or 300 cd/m^2 ($t(7)=6.76, p<.001$; $t(7)=3.01, p<.01$). The t tests were performed between two conditions of luminance under each size condition. Under the 0.04° condition, the ISI was significantly shorter in 300 cd/m^2 than in 3 cd/m^2 ($t(7)=2.20, p<.05$). Under 1.15° condition, no significance was found between the ISIs in 3 cd/m^2 and 300 cd/m^2 ($t(7)=0.59, p>.05$).

Experiment 3

This experiment examined the effects of the size and the luminance of the stimulus and their interacting effect on VISS, following a method similar to that of Ohmura (1986). The stimulus conditions were the same as in the second experiment, except that the duration of the stimulus was shortened. The peak values of ISI, namely, the values of ISI for producing optimal VISS were measured, following the method of limits.

Method

Subjects. The subjects were five male undergraduates from Kinki University in Kyushu. All had normal or corrected-to-normal vision. They had served as subjects in the first or second experiment.

Apparatus. The time schedules of flashing were controlled by a three-channel digital timer and a time-controller. The apparatus was the same as in the first experiment except for the above changes.

Stimulus display. The stimulus display was the same as used in the second experiment.

Procedure. A set of four panels, which were stimuli, was flashed in the same way as in the first experiment. The duration of the panel was always 30 ms, while the ICI was always 800 ms. The ISIs were 3 ms, 10 ms and every increment up to 200 ms. A trial started from the ISI selected at random out of a series of

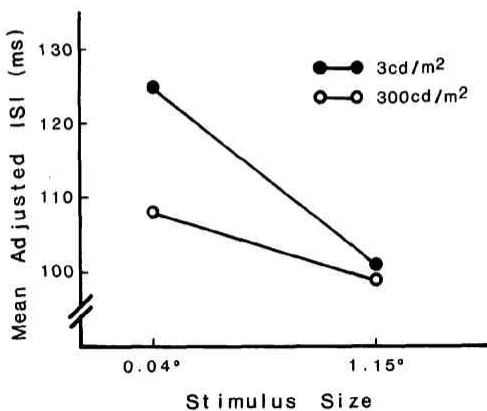


Figure 4. Mean adjusted upper limits of ISI for perceiving VISS for each luminance level as a function of stimulus size (Experiment 2).

the above ISIs. The subject was required to report whether the quality of VISS was "better than," "equal to," or "worse than" that in the previous ISI condition, for each step of ISI. A trial stopped, when the subject reported the first "worse quality of VISS" after a "better quality of VISS." He was tested in four blocks with a block for each of the four conditions. A block consisted of eight trials with four trials for each of the ascending and descending series in random order. The order effect was counterbalanced across subjects. Before the experiment, the subjects experienced the change of the appearance caused by a change of ISI with a trial under each ascending and descending series for each condition. Ten minutes were given for dark adaptation before the experiment. A five-minute rest was given between blocks.

The procedure was the same as in the second experiment except for these details.

Results

A peak value of ISI was determined on the basis of the clarity of VISS reported by the subject for each trial. The value was the mean ISI averaged between the ISIs for the last "better quality of VISS" and the first "worse quality of VISS." The first trials of

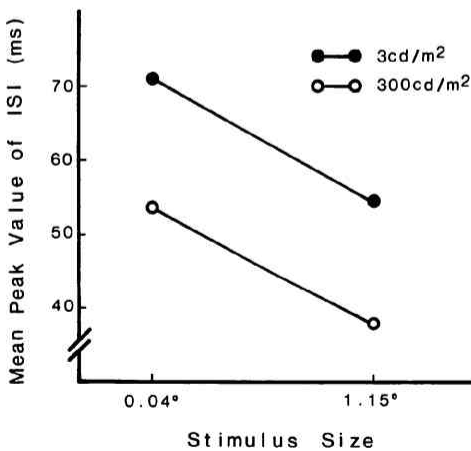


Figure 5. Mean peak values of ISI for perceiving optimal VISS for each luminance level as a function of stimulus size (Experiment 3).

ascending and descending series in each block were practice trials, and the other six trials were test trials. Mean peak values of ISI were used as data after being averaged for each subject through the six test trials in each condition. Figure 5 shows the mean ISIs averaged for five subjects in each condition of luminance as a function of the size of the stimulus. As is seen in Figure 5, the ISI is shorter in the 1.15° condition than in the 0.04° condition, irrespective of the luminance. The ISI is shorter for 300 cd/m² than for 3 cd/m², irrespective of the size.

The ISI data were analyzed by using a 2 × 2 (size × luminance) analysis of variance. A significant main effect of size was obtained ($F(1, 12)=18.71, p<.005$), as well as a significant main effect of luminance ($F(1, 12)=20.62, p<.001$). No interaction effect was found between size and luminance ($F(1, 12)=0.001, p>.05$).

Discussion

The main purpose of the present study was to examine the effects of the intensity (the size and the luminance) of the stimulus on VISS.

The upper limits of the ISI for producing VISS were measured in the first and the second experiments. Both of the experiments showed that the ISI decreased as the size of the stimulus increased. If we follow the notion that the size of the stimulus is contained in the Korte's intensity, according to Graham (1951), the results support Korte's second law.

The second experiment showed that the luminance of the stimulus affected the ISI in a different way depending on the size of the stimulus. The ISI was shorter in the high luminance condition (300 cd/m²) than in the low luminance condition (3 cd/m²), when the size was small (0.04°). There was no difference between the ISIs in high luminance and low luminance conditions, when the size was large (1.15°). The results support Korte's second law, when the size of the stimulus was

small. However, when the size was large, the results contradict the law.

After all, it was shown that the size and the luminance of the stimulus affected VISS generally according to Korte's second law. The result was compatible with Graham's (1951) notion that Korte's (1915) intensity includes not only the luminance but the size of the stimulus. It was also shown that the effects of the size and the luminance interacted with each other. This is not explained by Korte's second law. It is interpreted as follows. Ricco's law (Ricco, 1877) states that there is an inverse relation between the size and intensity required for detection of light. Piper's law (Piper, 1903) also states a similar relation between them with a little difference. According to these laws, a weak light that was not detectable when not large, is detectable when it is large. However, these laws do not apply beyond a certain size. Beyond that size, detectability of light remained constant irrespective of the size. The total effect of light over space, therefore, is detected by the visual system, but within certain size limits (Hood & Finkelstein, 1986). The system also functions similarly for perception of beta movement and VISS. The luminance and the size, in total, function as the intensity for producing VISS. When the stimulus is 1.15° in size and 3 cd/m^2 in luminance, the total intensity due to the size and the luminance already exceeds the critical intensity level of the visual system. Hence, the further effect of increasing luminance was not clear in the 1.15° condition.

The other purpose of the present study was to answer the question why the different effects of intensity on VISS were obtained between Ohmura (1986) and Watanabe (1992). The third experiment was performed to answer the question. The peak values of ISI were measured for producing optimal VISS, while the stimulus conditions were almost the same as in the second experiment. The third experiment was similar to Ohmura (1986), in that both attached importance to the goodness of VISS and examined its quality, one

aspect of VISS. Watanabe (1992) and the second experiment measured the upper limits of ISI for producing VISS. This was because they attached importance to a differentiation between VISS and beta movement in the presented order, and examined a transition point at which a change occurred between them, the other aspect of VISS. If the different effects were ascribed to the difference in the aspect of VISS examined between Ohmura (1986) and Watanabe (1992), the effects of intensity would not be found in the third experiment.

The results were as follows. The ISI decreased as the size of the stimulus increased, irrespective of the luminance of the stimulus. The ISI decreased as the luminance increased, regardless of the size. The results replicated those of the second experiment with the exception that no interaction was found between size and luminance.

Both of the second and the third experiments show the effects of intensity (size and luminance) in spite of the difference in the aspect of VISS examined. Ohmura (1986) did not demonstrate the effects of luminance, although she examined the same aspect of VISS as in the third experiment. The results indicate that the different effects of the intensity could be explained not by the difference in the aspect of VISS examined, but by differences in the method used.

The method used in the third experiment was different from that of Ohmura (1986) in two ways. First, the range of the varied intensity was larger in the present study than in Ohmura (1986). The range was from 13 cd/m^2 to 220 cd/m^2 in Ohmura (1986), but 3 cd/m^2 to 300 cd/m^2 in the present study. Watanabe (1992) has showed that the effect of luminance was clear in the low luminance condition, but not in the high luminance condition. In the present study, the clear effect of luminance resulted from the extended range of the luminance especially towards low luminance. The difference in range was sufficient to lead to different results. Second, ISI was

varied in small steps of 10 ms in the present study, while SOA was varied in rough steps (30, 70, 100, 130, 160, 200, and 260 ms) in Ohmura (1986). SOA is translated into ISI by subtracting the duration from SOA. The difference in ISI produced by the luminance was about 15 ms in the present study. The small steps of varied ISI was useful to obtain the differential effect of the luminance in the present study.

In summary, the present study showed the effects of the intensity on VISS that followed Korte's second law. The results support Ohmura's (1982) notion that VISS is functionally equivalent to beta movement and that it is, in form, regarded as a compound phenomenon consisting of two beta movements.

Many have tried to examine the effect of intensity on classical beta movement between two stimuli (Caelli & Finlay, 1981; Lane & Horne, 1964; Neff, 1936; Neuhaus, 1930; Ogasawara, 1936). In spite of Korte's law, they could not succeed in obtaining evidence of the effects of intensity. Ogasawara (1936) failed to show the effects of the size. Caelli and Finlay (1981) found no difference due to the luminance and size of the stimulus, and none due to the contrast between the stimulus and the background. The lack of evidence for intensity was because of the restrictions imposed by the experimental apparatus used. For example, in Caelli and Finlay (1981), they presented the visual stimuli on a CRT. It did not allow ISI to change in such small steps as in the present study, though intensity was varied in as large a range. As mentioned above, it is important to change the ISI in small steps to obtain the effects of luminance. At any rate, the effects of intensity were clearly demonstrated in the present study. This suggests the possibility that some effects of intensity should also be found in a careful study of classical beta movement between two stimuli.

Incidentally, how are the different results to be explained between the second and the

third experiments? Although the stimulus conditions were almost the same, the interaction between size and luminance was found in the second experiment, but not in the third experiment.

There was a little difference in methods between experiments. The duration was 50 ms in the second experiment, and 30 ms in the third experiment, in addition to differences in the measured phenomenon. The difference in duration was apparently small, but may have strongly affected the results.

Bloch's law (Bloch, 1885) states that there is an inverse relation between duration and the intensity required for detection of light. According to the law, a weak light that was not detectable when short in duration, is detectable when it is long in duration. However, the law does not apply beyond a certain duration. Bloch's, Ricco's, and Piper's laws mean that the total effect of light over space and time is detected by the visual system, but within a certain size and duration (Hood & Finkelstein, 1986). The system also functions similarly for the perception of beta movement and VISS. The luminance, size, and duration, in total, function as the intensity for producing VISS. Therefore, when the stimulus was 1.15° in size, 3 cd/m^2 in luminance, and 50 ms in duration, the total intensity of the size, luminance, and duration exceeded the critical intensity level of the visual system in the second experiment. The total intensity did not exceed the critical intensity level in the third experiment, when the stimulus was the same in size and, luminance as in the second experiment, but 30 ms in duration. Hence, the effect of increasing luminance was found in the 1.15° condition of the third experiment.

A preliminary experiment was performed before the third experiment to test whether a differential effect of the intensity is obtained with the duration of 50 ms. The experiment found that the peak value of the ISI was nearly zero in either condition of intensity at that duration and a differential effect was un-

likely. The duration was, therefore, shortened from 50 ms to 30 ms in the third experiment. In this way, the hypothesis was proved true. In addition, there still remains the possibility that the difference was caused by the measured phenomenon. The possibility should be tested in another study.

Finally, how should the results be related to the recent processing model? Many studies suggest that motion perception is mediated by two types of sub-systems: short-range and long-range processes. A short-range process is thought to occur at a relatively early level of the visual processing, whereas the long-range process is thought to occur at a higher level of the system. The short-range process is differentiated from the long-range process by its short-spatial range (below 0.25° of visual angle), brief temporal range (below 100 ms in ISI), motion aftereffects, and so forth (Anstis, 1978; Braddick, 1974; Cavanagh & Mather, 1989). The present study was concerned with the motion perception mediated by a long-range process because the stimulus configuration was long in spatial distance and long in ISI. If we are right in considering VISS as a kind of beta movement, the present study has indicated that the long-range process is affected by intensity in some level of the visual processing system.

How is VISS produced in the visual processing system? Studies about the correspondence problem are useful to answer the question (Ullman, 1979). The correspondence problem is as follows. When more than one element were contained in two different frames and alternated, how are the elements matched between the frames and to be perceived as a single object in motion? The problem is discussed in the split motion task, where R, a stimulus in the first frame, is replaced by A and B, two simultaneous stimuli in the second frame, flanking on either side of R with the ISI between the frames. When A and B are equal in distance from R, a split motion is seen from R to A and B. When they are not equal in distance, motion is seen

towards the stimulus with the shorter distance. The type of motion is supposed to be determined by not only the distance but the similarity in brightness, length, and orientation between the elements, and the timing.

Ullman (1979) states that the correspondence between the elements is governed by a certain built-in metric, termed "affinity" or correspondence strength. Motion correspondence is established between elements that have the largest affinity in the situation. The affinity is calculated primarily on the basis of the distance, the ISI, and the similarity between the elements. The affinity increases with a decrease in distance between the elements and with an increase in similarity. The effect of affinity is supposed to be clear in the short ISI but unclear in the long ISI.

The correspondence problem applies to VISS in the following way. Consider the affinities among the elements, A, B, C, and D. All the elements are the same. The distances between A and B and between C and D are equal and shorter than those between A and C, between B and C, and between B and D. For the short ISI, the affinity based on the distance predicts VISS, that is, two lights moving from A to B and from C to D. For the long ISI, however, the effects of affinity is not clear and therefore a light is seen moving in the presented order. In this way, the affinity explains why VISS is seen in the short ISI.

The effect of the ISI should be further examined. The stimulus configuration in the VISS task is not exactly the same as in the split motion task. In the split motion task, ambiguous stimuli, A and B, are presented simultaneously following R. In the VISS task, four stimuli is presented successively in the order of A, C, B, and D. Ambiguous stimuli, B and C are presented successively following A. Stimuli, B and D, are also presented in the same way following C. The ISI from A to B (i [A, B]) is always the total of 50 ms plus twice the ISI of A to C (i [A, C]). The ISI from C to D (i [C, D]) is also the total of 50 ms plus twice the ISI of C to B (i [C, B]). This means

that the difference between i [A, B] and i [A, C] is magnified as the ISI increases. The difference between i [C, B] and i [C, D] is also magnified. As a result, the difference is small between i [A, B] and i [A, C], and between i [C, B] and i [C, D] when the ISI is short. When the ISI is long, the difference is large between i [A, B] and i [A, C], and between i [C, B] and i [C, D].

According to Ullman (1979), the short ISI does not affect the affinity due to the other variables, and the increase in ISI makes the affinity more uniform. The obtained results in the present study are consistent with Ullman's theory even if two ambiguous stimuli are presented successively. The results also suggest that the ISI has strong relations with the affinity at the longer ISI. For example, the ISI decreased gradually in accordance with increasing the size of stimulus. This means that the ISI affects the affinity differentially depending on the stimulus condition. Remember that VISS is produced easily when the ISI is short. In addition, VISS is exactly a motion correspondence produced by the affinity. The results indicate that the affinity increases with a decrease in ISI between the elements.

The present study also showed that the ISI decreased as the intensity (size and luminance) increased. This means that the affinity should be strengthened by shortening the ISI in accordance with increasing the intensity. If it is right that the ISI contributes to the affinity in the above-mentioned way, the intensity (size and luminance) is supposed to decrease the affinity.

References

- Anstis, S.M. 1978 Apparent movement. In R.L. Held & H.W. Leibowitz (Eds.), *Handbook of sensory physiology*. Vol. 8. *Perception*. New York: Springer-Verlag. Pp. 655-673.
- Braddick, O. 1974 A short-range process in apparent motion. *Vision Research*, **14**, 519-528.
- Bloch, A.M. 1885 Experiences sur la vision. *Société de Biologie (Paris)*, **37**, 494-495.
- Bregman, A.S., & Achim, A. 1973 Visual stream segregation. *Perception and Psychophysics*, **13**, 451-454.
- Bregman, A.S., & Campbell, J. 1971 Primary auditory stream segregation. *Journal of Experimental Psychology*, **89**, 244-249.
- Caelli, T., & Finlay, D. 1981 Intensity, spatial frequency, and temporal frequency determinants of apparent motion: Korte revisited. *Perception*, **10**, 183-189.
- Cavanagh, P., & Mather, G. 1989 Motion: The long and short of it. *Spatial Vision*, **4**, 103-129.
- Dannenbring, G.L., & Bregman, A.S. 1976 Effects of silence between tones on auditory stream segregation. *Journal of Acoustic Society of America*, **59**, 987-989.
- Graham, C.H. 1951 Visual perception. In S.S. Stevens (Ed.), *Handbook of experimental psychology*. New York: Wiley. Pp. 869-920.
- Hood, D.C., & Finkelstein, M.A. 1986 Sensitivity to light. In K.R. Boff, L. Kaufman & J.P. Thomas (Eds.), *Handbook of perception and performance*. Vol. 1. *Sensory processes and perception*. New York: Wiley & Sons. Pp. 5-1-5-66.
- Kahneman, D., & Wolman, R.E. 1970 Stroboscopic motion: Effects of duration and interval. *Perception and Psychophysics*, **8**, 161-164.
- Korte, A. 1915 Kinematoskopische Untersuchungen. *Zeitschrift für Psychologie*, **72**, 193-296.
- Lane, W.P., & Horne, E.P. 1964 Stimulus intensity and position effects on apparent movement. *Journal of General Psychology*, **71**, 87-92.
- Neff, W.S. 1936 A critical investigation of the visual apprehension of movement. *American Journal of Psychology*, **48**, 1-42.
- Neuhaus, W. 1930 Experimentelle Untersuchungen der Scheinbewegung. *Archiv für Gesamte Psychologie*, **75**, 315-458.
- Ogasawara, J. 1936 Effects of phenomenal distance on beta movement. *Japanese Journal of Psychology*, **11**, 109-122. (In Japanese)
- Ohmura, H. 1982 Visual stream segregation and β movement. *Japanese Journal of Psychology*, **53**, 50-53. (In Japanese with English abstract)
- Ohmura, H. 1986 The role of stimulus intensity, color, and form in visual stream segregation. *Japanese Psychological Research*, **28**, 21-29.
- Piper, H. 1903 Über die Abhängigkeit des Reizwertes buchtender Objekte von ihrer Flächen-bezw. *Zeitschrift für Psychologie und Physiologie der Sinnesorgane*, **32**, 98-112.

- Ricco, A. 1877 Relazione fra il^o minimo angolo visuale e l'intensita luminosa. *Annali di Ottalmologia*, **6**, 373-479.
- Ullman, S. 1979 *The interpretation of visual motion*. Cambridge, Mass.: MIT Press.
- Watanabe, I. 1981 The effect of the spatial distance upon visual stream segregation. *Japanese Journal of Psychology*, **52**, 57-60. (In Japanese with English abstract)
- Watanabe, I. 1992 Effect of stimulus intensity on visual stream segregation. *Japanese Journal of Psychology*, **63**, 346-349. (In Japanese with English abstract)

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