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EFFECTS OF STIMULUS VELOCITY AND STIMULUS DENCITY UPON THE VISUAL MOTION AFTEREFFECT

By

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The duration and the velocity of the visual motion aftereffect (MAE) were measured under the fairly wide variation of the density and the velocity of the grating patterns. Results obtained were as follows: (1) the two indices of the MAE showed almost the same characteristics, (2) the MAE strongly depended upon the stimulus velocity except for the gratings with excessively high or low stimulus density, (3) long lasting and fast MAEs were obtained for the gratings with the median stimulus density, and (4) the MAE reached the maximum at the low temporal frequency of $1 \sim 4$ lines/sec for any gratings. It was discussed that these results could explain the apparent inconsistency existing in the previous data on the subject.

INTRODUCTION

Although many studies have been reported concerning the visual motion aftereffect (MAE), the results are not necessarily consistent. This is especially the case with the experimental data on the velocity or the speed of the seen motion after-effect (MAE-velocity).

As for the relationship between the velocity of the inducing objects (stimulus velocity) and the MAE-velocity, it is said, on the one hand, that the MAE-velocity first increases and then decreases with the acceleration of the stimulus velocity (Borschke & Hescheles, 1902; Cords & von Brücke, 1907; Wohlgemuth, 1911), and on the other hand, that the MAE-velocity is independent of the stimulus velocity, being constant in spite of the increase of it (Johansson, 1956). A decade ago Dureman reanalyzed the Johansson's raw data and found that almost all subjects who participated in Johansson's experiment showed the systematic but remarkably modest increase of the MAE-velocity according as the stimulus velocity increased (Dureman, 1962). Dureman conducted an experiment taking after Johansson's, obtaining similar but not the same results.

As pointed by Dureman in his discussion, there are some differences in their experimental conditions. The greatest differences in their settings are the following three: (1) the size of the stimulus disk (a. Johansson-15°20' vs. b. Dureman-3°06'), (2) the background (a.-grey vs. b.-black), and (3) the distance between radial lines on the disk (a.-1° vs. b.-30°).

In the preliminary experiment in which a well-trained graduate served as a subject, the relationship between the stimulus velocity and the MAE-velocity was re-examined under the experimental condition lying between Johansson's and Dureman's. The disk on the white background was used as the stimulus display, its size being 5°44' in visual angle and the distance between radial lines on it, 10°. In measuring the MAE-velocity, "the method of intermittent stimulation" suggested by Johansson was adopted. The result was that the MAE-velocity increased at first and then reached the maximum and gradually decreased with the increase of the stimulus velocity, being consistent with the conclusion obtained by the several previous investigators.

As a result of scrutinizing the experimental conditions of these studies, it was expected that the inconsistency existing in the results obtained may be attributed to the stimulus variable of the distance between the radial lines which corresponds to the density of the stimulus pattern. In most of the above mentioned studies, however, it seems that the only one variable such as the stimulus velocity was varied, keeping the other such as the stimulus density constant, or *vice versa*. In the present study it was aimed to make clear entirely how the systematical changes of these two stimulus variables influence not only the MAE-velocity but the duration of the visual MAE (MAE-duration).

Method

Subjects: 3 graduates and 2 undergraduates in our psychological laboratory served as subjects. All of them were trained for more than two hours in advance of the experimental session in order to get the stability of measurements.

Apparatus: The blockdiagram of the whole apparatus is illustrated in Fig. 1. Photographs 1., and 2. show the whole and the parts of the actual appratus. Each channel of the three channel tachistoscope (TKK Co. Ltd.) was used as the moving stimulation field (Ch. 1), the test field or the projection field (Ch. 2), and the background field (Ch. 3), respectively. Each field has opaque milk-white plates of vinyl chloride, being accompanied by the lights A, B (the day light fluorescent tubes), and C (the white neon tube) behind them. Only when these tubes are lighted, the stimulus patterns produced by the diffuse light are presented to *S*s. A and B are lighted alternately according to the time arrangement predetermined by the timer, T, while C is continuously lighted during all over the experiment. The structure of the background field is as follows: a dim red circle point for the fixation is in the center, and a square framework (17 cm×17 cm, 11°28'×11°28') composed of 5 mm wide white lines produced by the light is around the fixation point. This framework was employed in order to inhibit the occurrence of the apparently induced movement of the fixation point. Both the moving stimulation field and the test field have the aperture (15 cm ×2 cm, 10°07'×1°21') 2 cm to the left of the fixation point in the background. When A or B is turned on, the moving stimulus pattern or the test pattern is observed through this aperture. When both A and C are lighted, the stimulus display shown

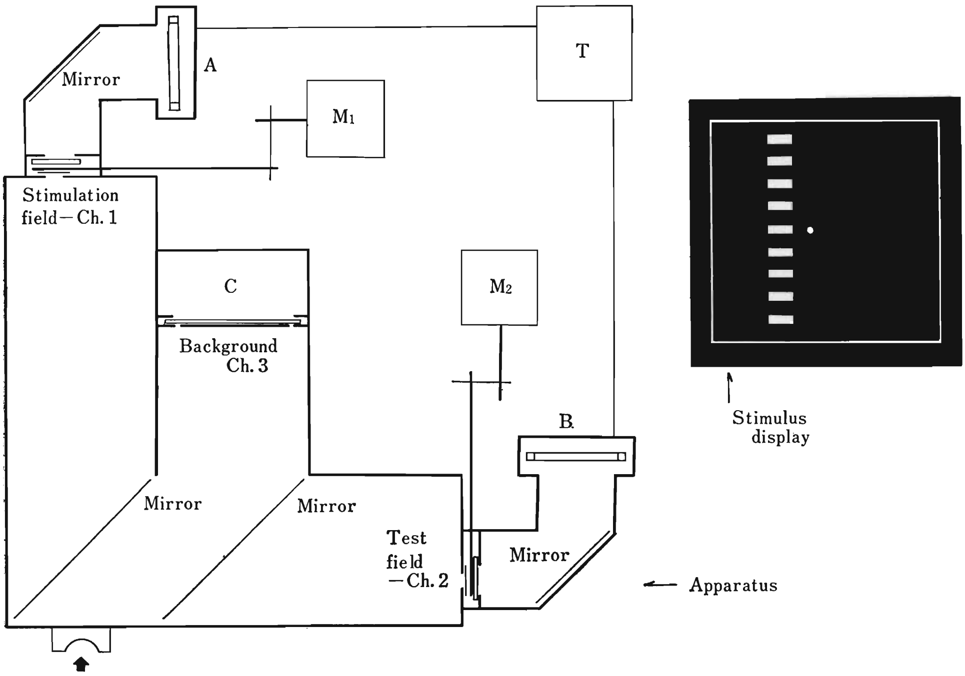

Fig. 1. Diagram of whole apparatus and stimulus display.

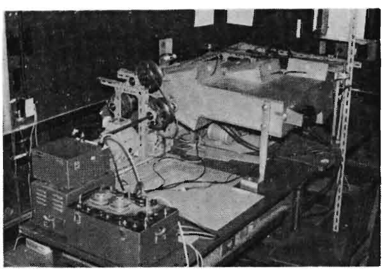

Photo. 1

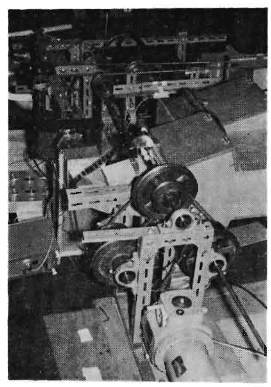

Photo. 2.

Photo. 1 The whole of the apparatus.
Photo. 2 The part of the apparatus.

in the right illustration in Fig. 1. can be seen.

The moving stimulus pattern and the test pattern were made of the photographic negatives with high and low transparency, and the tailends of a roll of film were connected by means of the film cement. The moving stimulus patterns are gratings with the spatial light-dark-ratio (LDR) of 1:1. The test pattern is the checkerboard-like pattern on which small dark squares are scattered regularly. The luminance of the light area and that of the dark area on the moving stimulation field are 0.52 cd/m^2 and 0.02 cd/m^2, respectively, and those on the test field are 0.46 cd/m^2 and 0.02 cd/m^2, respectively.

The grating pattern was connected with the motor, M_1 (Ringcone vari-speeder, Type SCM 100B5) through the several intermediating pulleys and belts. Wide range variations of the velocity of the gratings were obtained by the combinations of the pulleys and by the M_1 itself. The test pattern was connected with the other motor, M_2 (the same type as M_1) by means of the pulleys, belts and a set of gears, but M_2 was not used in the measurement of the MAE-duration.

Procedure: Six conditions of the stimulus density of the grating patterns were employed as shown in Table 1. The stimulus density is described in terms of mm/cycle, minutes of arc/cycle and lines/minutes of arc. The velocity of the grating pattern was varied over 9 logarithmic steps: V.1.–0.13° (degrees of arc)/sec, V.2.–0.26°/sec, V.3.–0.51°/sec, V.4.–1.02°/sec, V.5.–2.05°/sec, V.6.–4.10°/sec, V.7.–8.20°/sec, V.8.–16.40 °/sec, and V.9.–32.80°/sec. Each stimulus velocity was checked by the timecounter (TKK Digitimer) before every trial. The orientation of the grating patterns was horizontal and these gratings moved only downward.

Table 1. Stimulus density of the grating patterns used in the present study.

No of Gr.	mm/cycle	min of arc/cycle	lines/min. of arc
Gr. 1	60. 14	243. 25	0. 0041
Gr. 2	30. 03	121. 46	0. 0082
Gr. 3	14. 96	60. 51	0. 0165
Gr. 4	7. 43	30. 05	0. 0333
Gr. 5	3. 71	15. 01	0. 0666
Gr. 6	1. 93	7. 90	0. 1266

Six grating patterns were not presented to all *S*s. It was the only one *S* whom all of the six gratings were presented to. Referring to the other *S*s, the gratings in odd numbers (Gr. 1., Gr. 3., and Gr. 5.) were presented to one *S* in the measurements of the MAE-duration and to two *S*s in those of the MAE-velocity, and the gratings in even numbers (Gr. 2., Gr. 4., and Gr. 6.) were presented to two *S*s in the former case and to one *S* in the latter case.

Measurement of the MAE-Duration: The duration of the prestimulation by the moving grating pattern was thirty seconds. The MAE-duration was measured by means of the time-counter which started immediately after the termination of the prestimulation and stopped when the *S*s pushed the button at hand. The intertrial interval was four minutes, which had been predetermined by T. This interval was also held in the measurement of the MAE-velocity.

Measurement of the MAE-Velocity: "The method of intermittent stimulation" and "the method of compensation" employed by Cords & von Brücke were adopted. After prestimulation of thirty seconds, twenty five pairs of test-phase (0.8 sec)-restimulation-phase (4 sec) were repeated (the method of intermittent stimulation). In the course of this repetition *S* set in motion the test pattern in the opposite direction to that of the MAE and adjusted the velocity of the test pattern in the test-phase until the pattern appeared to be motionless (the method of compensation). In the present study only ascendent series were employed, i.e. the series starting from the velocity of the test pattern which was so slow that the test pattern appeared to be moving in the same direction as that of the MAE and gradually increasing it. The velocity of the test pattern was adjusted by *S* by turning the knob connecting with the speed regulator of M_2. This final velocity of the test pattern determined in this way was taken as the MAE-velocity.

Each of the two indices of the MAE-duration and the MAE-velocity was measured, extending over two days under one condition out of six stimulus densities. The measurements in a day began with a series of three trials for the standard stimulus which was the combination of Gr.3.–V.5. for the *S*s to whom the gratings in odd numbers were presented and which was the combination of Gr.4.–V.4. for those whom the gratings in even numbers and all of the gratings were presented to (pre-test). It took about fifteen minutes to make these measurements. And then the trials for a given grating were made at the nine stimulus velocity steps in a randomized order and this series of nine trials was repeated three times (nearly an hour and a half). Finally the three trials to the same standard stimulus as used in the pre-test were made (post-test, 15 min). The period of the experiment in a day was nearly two hours. When the values obtained from the first three measurements for the standard stimulus differed greatly from those given on the first day, that day's experiment was discontinued.

It took approximately a month to terminate all the experiments for the *S* who gave the data of both the MAE-duration and the MAE-velocity under all the conditions of the stimulus density (6 stimulus densities $\times$2 indices$\times$2 days).

The distance between *S*'s eyes and the each field was 85 cm. Binocular vision was employed. The eyes were dark-adapted for nearly 5 minutes.

RESULTS

As the raw data obtained over a fairly long period showed some changes in values day after day, they were corrected according to the following ways. The arithmetic mean of six values for the standard stimulus obtained before and after the experiment in a day was divided by that of those values on the first day and the ratio calculated in this way was multiplied by the raw data obtained on that day. These corrected data were used for drawing the figures.

The results are presented in Fig. 2. and Fig. 3. as a function of the stimulus velocity, taking the stimulus density as a parameter. In the graph each point and vertical line on the curve are the mean and the range of the six values. The data of *S*, M were obtained from all the gratings, those of *S*, J from the gratings in odd numbers, and those of *S*, K from the gratings in even numbers. As the rest of the *S*s show almost the same results, their curves were not presented.

It is known from these graphs, first, that both the MAE-duration and the MAE-

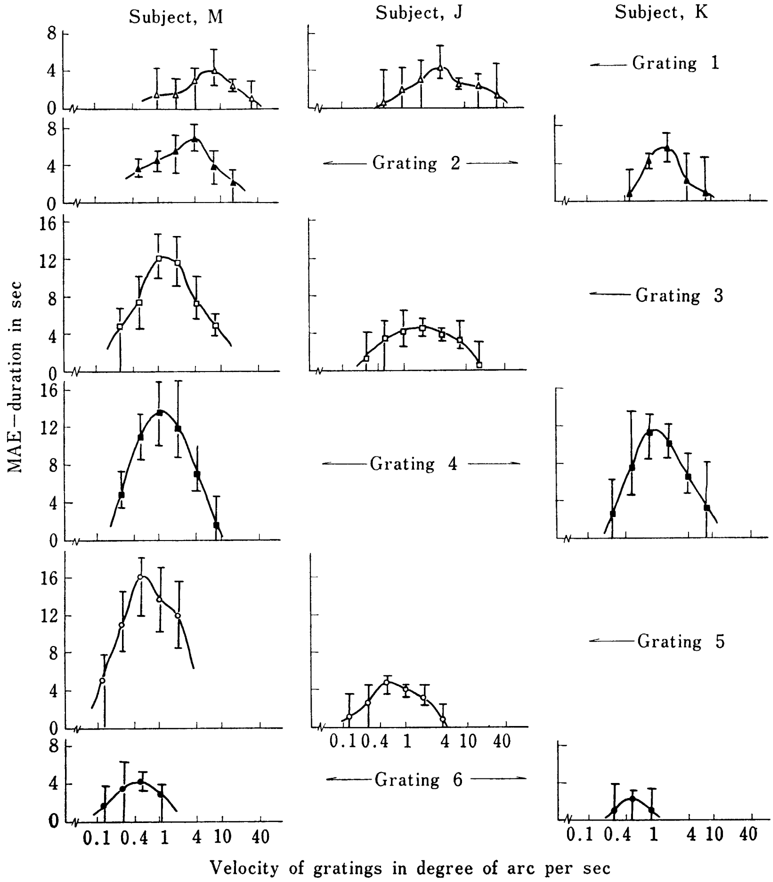

Fig. 2. MAE-duration as a function of the volocity of gratings

velocity first increase and then reach the summit and finally decrease with the increase of the stimulus velocity for any grating pattern used in this study. This is, however, not remarkable in the curves of the MAE-velocity for Gr.1., Gr.2., and Gr.6. Secondly, paying attention to the maximum MAE, the MAE lasts longer and its velocity becomes faster when Gr.3., Gr.4., and Gr.5. are presented to the *S*s than when Gr.1., Gr.2., and Gr.6. are presented although this is not the case with the MAE-velocity of *S*, J. Compared with the median gratings like Gr.3., Gr.4., and Gr.5., both Gr.1. and Gr.2. have low stimulus density (coarse gratings) while Gr.6. has high stimulus density (fine grating). It is known from this that the gratings having the median stimulus density facilitate the occurrence the MAE and conversely those gratings of which stimulus density is too low or too high suppress that of the MAE.

When the images of the grating patterns move on the retina, the temporal frequency (lines/sec) can be calculated, which is the number of the lines passing through a given point on the retina per a unit of time. The extent of the MAE as a function of

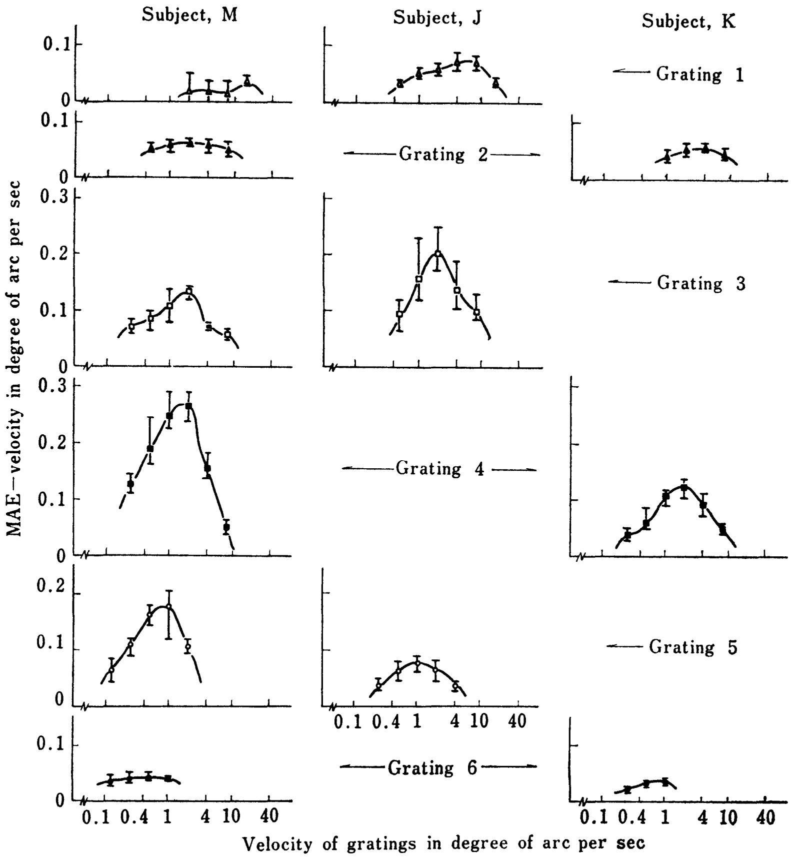

Fig. 3 MAE-volocity as a function of the volocity of gratings

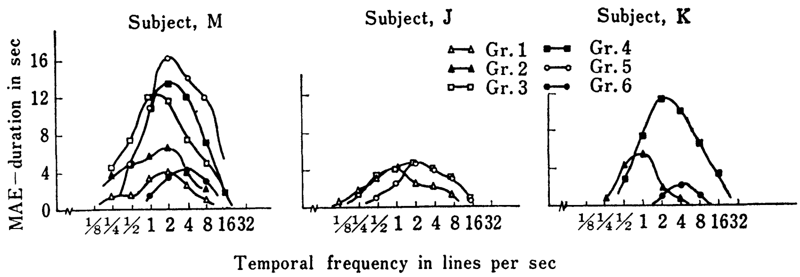

Fig. 4 MAE-duration as a function of the temporal frequency

this temporal frequency is shown in Fig. 4. and Fig. 5., taking the stimulus density of the gratings as a parameter. It seems to be clear that each curve has a maximum point at the relatively low temporal frequency of 1 ~4 lines/sec and the MAEs do not occur at the temporal frequency of less than 1/8 lines/sec nor more than 16 lines/sec.

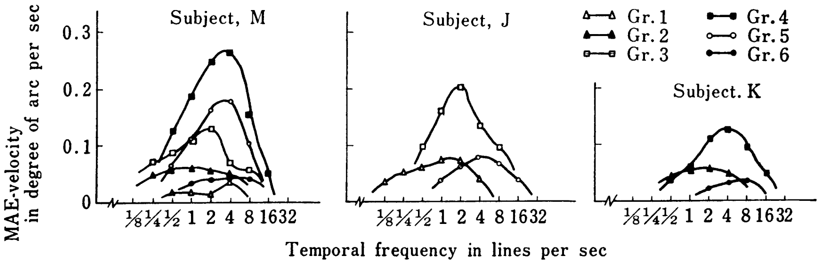

Fig. 5 MAE-velocity as a function of the temporal frequency

Discussion and Conclusion

The inconsistency that has been found in the experimental data on the relationship between the stimulus velocity and the MAE-velocity may be explained according to the results obtained in the present study. It seems that the apparent disagreement in these results originates in the differences of the experimental conditions employed. Johansson used a disk stimulus with many radial lines on it, which corresponds to Gr.6. in the present study, and on the contrary, Dureman employed a disk with several lines, corresponding to Gr. 1. and Gr. 2. The stimulus conditions employed by them are near the two extreme ends on the dimension of the stimulus density which is necessary to produce the MAE. The present data are in accordance not only with their results, but with the results obtained by the investigators before them. Considering the results in this way, it might be a question to generalize the basic mechanisms of the MAE from the results obtained under these extreme stimulus conditions.

Several studies have been reported which tried to clarify the relationship between the stimulus density and the MAE (Borschke & Hescheles, 1902; Szily, 1905; Cords & von Brücke, 1907; Wohlgemuth, 1911). Although the results of these studies differ from one another, these apparently different results are not always contradictory if they are examined all over again on the basis of the present data. It might be said that the dynamic relationships of the stimulus conditions to produce the MAE could be clarified through the wide variation in the stimulus density and the stimulus velocity of the grating patterns.

In interpreting the present results, several studies made in recent years are instructive. First, there are a number of studies for measuring the response characteristics of the visual system to the stimuli on which the luminance is distributed in the form of the periodical wave patterns. The contrast thresholds for the moving spatial sine-wave gratings decreased for the median spatial frequencies (the stimulus density) at slow speeds (van Nes, Koenderink, Nas, & Bouman, 1967; van Nes, 1968; Watanabe, Mori, Nagata, & Hiwatashi, 1968). This finding corresponds to the present results that the extent of the MAE augments for the gratings with the median stimulus density. Secondly, the study must be noted which dealt with the luminance threshold for the detection of the direction of movement given by the same grating pattern as used in the present study (Crook, 1937). The result of this study was that the luminance threshold for the discrimination of the direction of movement decreased most at fairly slow rates (the temporal frequency) and increased with the increase of the temporal frequencies. This is consistent with the present result that the extent of the MAE becomes maximum at the temporal frequencies of 1 ~4 lines/sec. This coincidence may probably be due to the so-called "Brücke-Bartley effect". The third is the study which is concerned with the effect of the information content upon the MAE (Dixon & Meisels, 1966). Dixon et al. showed that the high information content field exceeded the low one in the extent and the duration of the MAE.

Both the contrast threshold for the moving sine-wave grating patterns and the luminance threshold for the detection of the direction of moving gratings are taken as the sensitivity indices of the visual systems to the moving gratings. Considering the fact that the rise and fall of the sensitivity to moving stimuli corresponds to the increase and the decrease of the MAE and the fact that the information content of the moving stimuli affects the MAE, it may be said that the extent of the MAE is determined by the effectiveness of the moving stimuli to the visual system. When a moving stimulus which stimulates the visual system forcefully is given to the system, the system raises its sensitivity to the stimulus, resulting in its full excitation. When the moving stimulus is stopped, the extent of the MAE would increase, as a result, so far as the hypothesis suggested by Sutherland (1961) and others is valid (Barlow & Hill, 1963; Sekuler & Pantle, 1967).

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