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Motion and depth perception with dichoptic-sequential presetntation of random-dot patterns

ランダムドット・パターンの両眼分離・継時刺激における
運動知覚と奥行知覚

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MOTION AND DEPTH PERCEPTION

WITH

DICHOPTIC-SEQUENTIAL PRESENTATION OF RANDOM-DOT PATTERNS.

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ABSTRACT

It is known that apparent motion can not be perceived when two patterns of random-dot kinematograms are presented dichoptically, although classical apparent motion can be perceived under dichoptic and sequential(D-S) presentation(Braddick, 1974). These results suggest that D-S motion perception is dependent on dot-density. However, it is also known that stereoscopic perception is possible with D-S presentation when SOA is small(Ogle, 1963). The relationship between the two perception has not been clarified, since all past D-S studies examine either only motion or only depth. To clarify the relationship, relative frequency and accuracy of motion and depth perception were measured while varying dot-density (1-50%), SOA(15-240 ms, ISI=0, SOA=duration), and disparity(3-48'). Two 6° x 6° random-dot patterns(dot-size=3') with a central disparate square target and an identical background were used. Each pattern was presented only once. The subject's task was to say whether the target was in depth or in motion, and then to discriminate direction of depth(near/far) or motion (right/left).

Depth perception was dominant at shorter SOAs(<100 ms), while motion perception became dominant at longer SOAs(>100 ms). Relative frequency of depth decreased, while that of motion increased as SOA was increased. At intermediate SOAs, depth perception was more frequent with high dot-densities, but motion was more frequent with low dot-densities, i.e. depth favors high, but motion favors low dot-density. As for accuracy, it was nearly 100% for depth in favorable conditions, but for motion, it was about 50% in most conditions. The perceived direction depended almost completely on eye-order, i.e. rightward motion was perceived when the first stimulus was presented to the right eye. Better motion-accuracies were obtained only with very low dot density, long SOA, and large displacement, i.e. conditions favorable for the classical motion. It is concluded that (1)Dichoptic information is fed primarily into the stereo system when SOA is short, and that (2)the short-range motion mechanism does not seem to functio under D-S presentation; motion perception under D-S presentation is either eye-order-dependent motion or classical apparent motion.

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OBJECTIVES

(1)To identify the condition in which we see depth or motion with dichoptically and sequentially presented random-dot patterns.
(2)To examine if dichoptic and sequential presentation technique can isolate the long range motion mechanism from the short-range mechanism.

INTRODUCTION

We see motion from temporally disparate images, and depth from interocularly disparate images. What do we see, however, when we are confronted with temporally and interocularly disparate images such as shown in Fig. 1? If the difference between the two images are evaluated as interocular disparity, we should see depth. If, however, the difference is interpreted as temporal difference, we should see motion. To clarify the relationship between motion and depth perception for temporally and interocularly disparate images is the first objective of this study. The relationship between the two percepts has not yet been clarified, since all past studies examine either only motion or only depth.

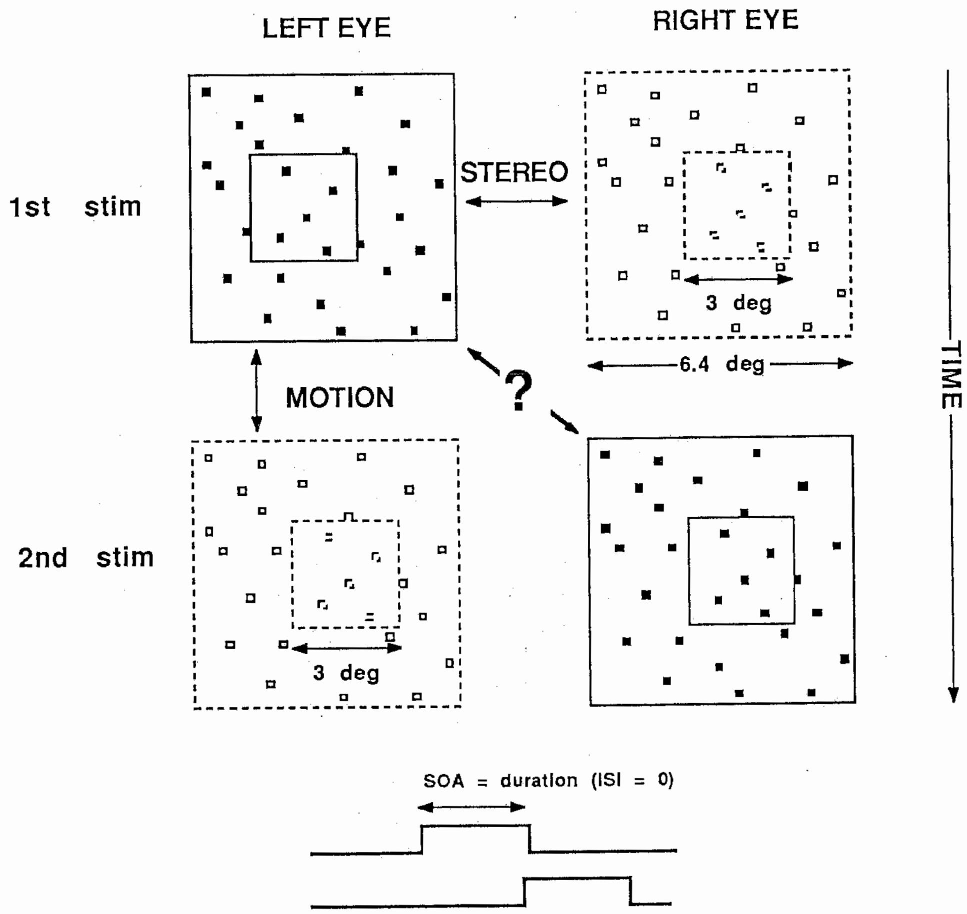

Fig. 1 Dichoptic-Sequential presentation.

An example of temporally and interocularly disparate images. This figure also shows the stimulus arrangement in the experiments in this study.

Past studies have shown the following three facts:
(1) stereoscopic depth perception is possible with sequential presentation of image pairs as long as SOA is short(SOA < 100ms, Dodwell and Engel, 1963; Ogle, 1963),
(2) classical apparent motion with two simple figures such as lines or disks is perceived with dichoptic presentation(Shipley et al., 1945), and
(3) apparent motion with random-dot patterns (random-dot kinematograms) is not perceived(Braddick, 1974).

The recent development of stereo TVs using LCD glasses is based on the first phenomenon. The second and third phenomena indicate that the short-range motion mechanism is insensitive to interocular motion stimulation, but that long-range mechanism is sensitive. According to Braddick(1974), the short-range mechanism mediates motion of complicated patterns such as random-dot patterns for a limited spatial range, whereas the long-range mechanism mediates motion of simple figures over a wide spatial range. Braddick also claims that the insensitivity to dichoptic motion is an important characteristic of the short-range motion mechanism. If these assumptions are valid, we should see motion with interocular random-dot kinematograms when dot-density is reduced.

EXPERIMENT I: MOTION-DEPTH PREFERENCE

In the first experiment, relative frequency and accuracy of motion and depth perception were measured with sequentially presented Julesz's random-dot stereograms while varying dot-density and SOA(Fig. 1). Disparity was fixed at 12 arc min, which gives a good motion or depth perception of the central target when the patterns are shown as regular kinematograms or stereograms. The subject was asked (1)to tell whether the target was seen in motion or in depth, and (2)to discriminate direction of depth(near/far) or motion (right/left).

Stimulus

Display	66 Hz non-interlace CRT(Masscomp MC5600)
Dot size	3 min (white dots on black background)
Pattern size	6.4 x 6.4 deg (128 x 128 dots)
Target size	3.0 x 3.0 deg (60 x 60 dots)
Dot density	0.2, 1, 10, 50%
SOA	15, 30, 60, 120, 240 ms
Displacement	12 min (4 dots)

Results

The results indicate depth perception is dominant at shorter SOAs, while motion perception becomes dominant at longer SOAs(Fig. 2). At intermediate SOAs, motion was seen more frequently with low density patterns, but depth was seen more frequently with high density patterns. Because of this effect of dot-density, the transition between depth and motion perception takes place at shorter SOA for low dot-density, and at longer SOA for high dot-density. The transition for 50% density pattern is at 180 ms, while that for 1% density is at less than 50 ms.

As for accuracy(Fig. 3), it was nearly 100% for depth at shorter SOA where depth was preferred, but for motion, it was about 50% even at the longest SOA where motion was strongly preferred. Further analyses of the data revealed that the perceived direction depended almost completely on eye-order, i.e. which eye sees the the first pattern. This eye-order effect will be described further in the next section.

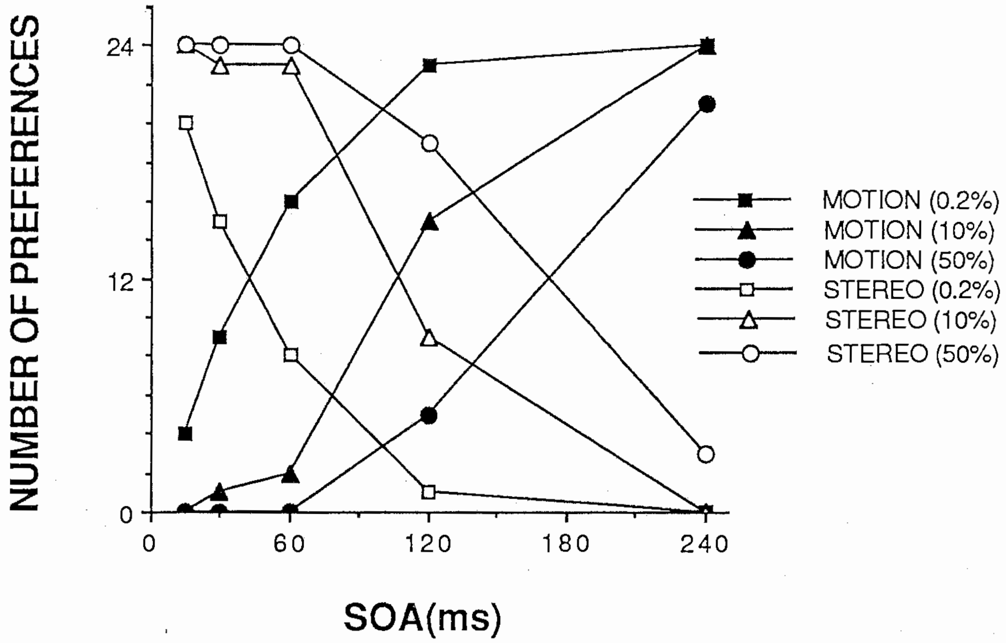

Fig. 2 Motion/depth preference.

The number of trials in which motion or depth was preferred(total 24 trials).

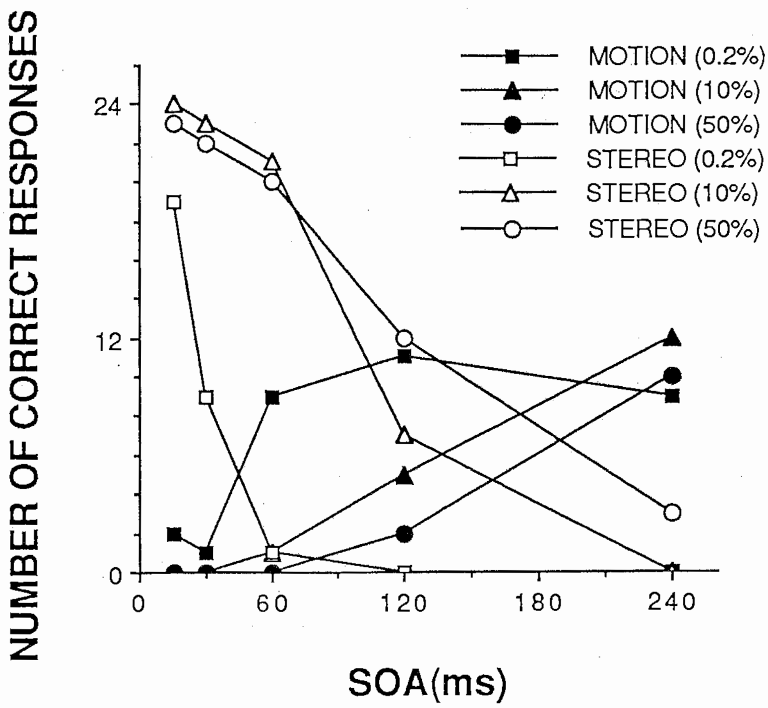

Fig. 3 Motion/depth accuracy.

Number of correct motion/depth direction judgementsin preferred trials.

EXPERIMENT II: FORCED MOTION EXPERIMENT

The preference shown in the first experiment does not necessarily mean that only one kind of perception is possible, because the subject often saw both motion and depth simultaneously. To evaluate performance of depth or motion discrimination when they are not dominant, two additional experiments were conducted. In these experiments, subjects were forced to judge the direction of either only motion or only depth in all trials, even if the other percept was prevailing. The pattern displacement in these experiments was not a fixed value, but was varied in several steps. Except for these changes, the method of these experiments resembled that of the first experiment.

In the forced-motion experiment, the random-dot patterns did not have the central target. Instead, the whole pattern was shifted with wrap-around. Because of this, subjects almost never had depth impression, and the stimuli were seen either in motion or with nondirectional flicker.

Stimulus

Display	66 Hz non-interlace CRT(Masscomp MC5600)
Dot size	3 min (white dots on black background)
Pattern size	6.4 x 6.4 deg (128 x 128 dots)
Target size	None (Full field window motion)
Dot density	0.1, 1, 10, 50%
SOA 1	5, 30, 60, 120, 240 ms
Displacement	0, 3, 6, 12, 24, 48, 72, 96 min (0, 1, 2, 4, 8, 16, 24, 32 dots)

Results

The results at 240 ms SOA are shown in Fig. 4. Accurate motion discrimination was obtained only in conditions with long SOA, low dot-density, and larger spatial displacement, or in other words, in conditions presumably favorable for classical apparent motion. On the other hand, in conditions suitable for short-range motion, that is at displacements less than 20 min, performance was at chance level. It does not mean the motion was invisible, or the subject lacked confidence in his decision. The subject mostly perceived strongly directional motion, especially at low to intermediate dot-densities. At 50%, subjects often failed to perceive directional motion; they perceived flicker.

Further analysis of the data revealed that motion judgement at smaller displacements is solely dependent on which eye sees the stimulus first, regardless of the spatial shift in the pattern. The relationship between this eye-order in presentation and perceived direction is illustrated in Fig. 5. There are four combinations of stimulus-presentation order to the two eyes and direction of physical displacement of the patterns. These four combinations can be grouped into two categories -- motion toward the eye which receives the first stimulus, and motion toward the eye which receives the second stimulus. When the data is replotted according to these two categories(Fig. 6), it was found that, for shorter displacements, judgements are almost always correct when physical motion is toward the first eye, and almost always incorrect if motion is toward the second eye. For instance, rightward motion was perceived when the first stimulus was presented to the right eye.

At 50% dot-density, the eye-order effect was weaker. This is probably because the subject saw flicker instead of motion in many trials, and the eye-order effect was evident only when the subjects saw motion.

These results indicates that the long-range motion mechanism can be isolated by dichoptic-sequential stimulation. Correct directional motion was perceived with stimuli suitable for long-range motion, but for stimuli suitable for short-range motion, although motion impression was available, perceived direction was solely dependent on presentation order, not at all on pattern displacement. The effect of dot-density and SOA on the upper displacement limit with regular monocular random-dot kinematograms will be examined later in Experiment IV.

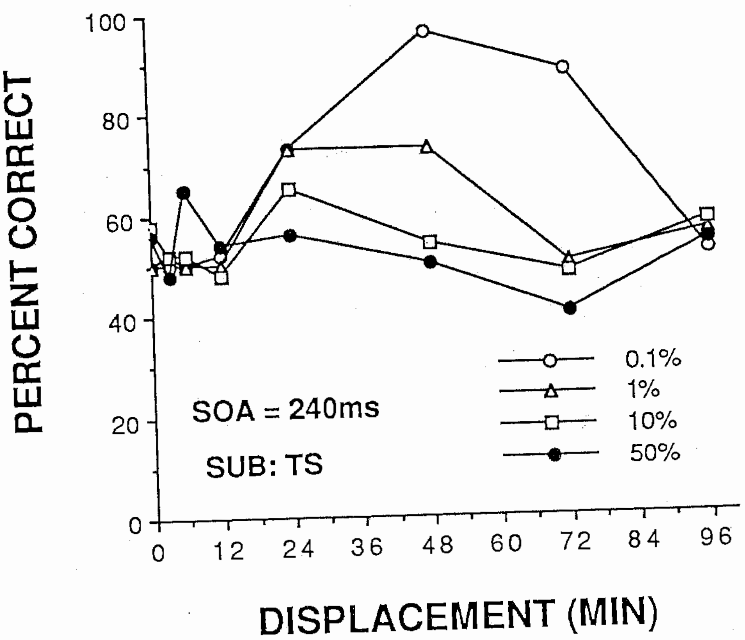

Fig. 4 Motion judgement at SOA=240 ms.

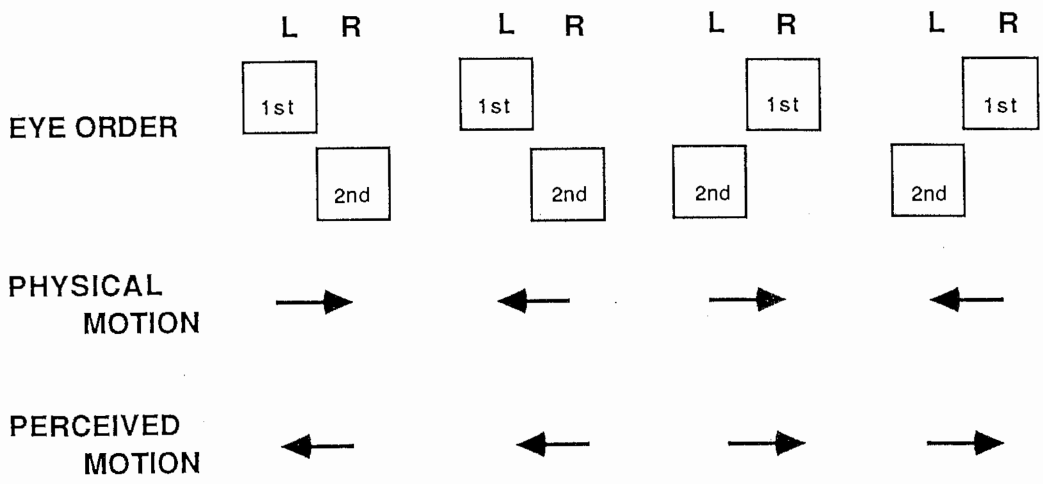

Fig. 5 Relationship between eye-order and perceived motion.

There are four possible combination of eye-order(first row) and direction of physical displacement of patterns(2nd row). The perceived direction (third row) is determined by eye-order.

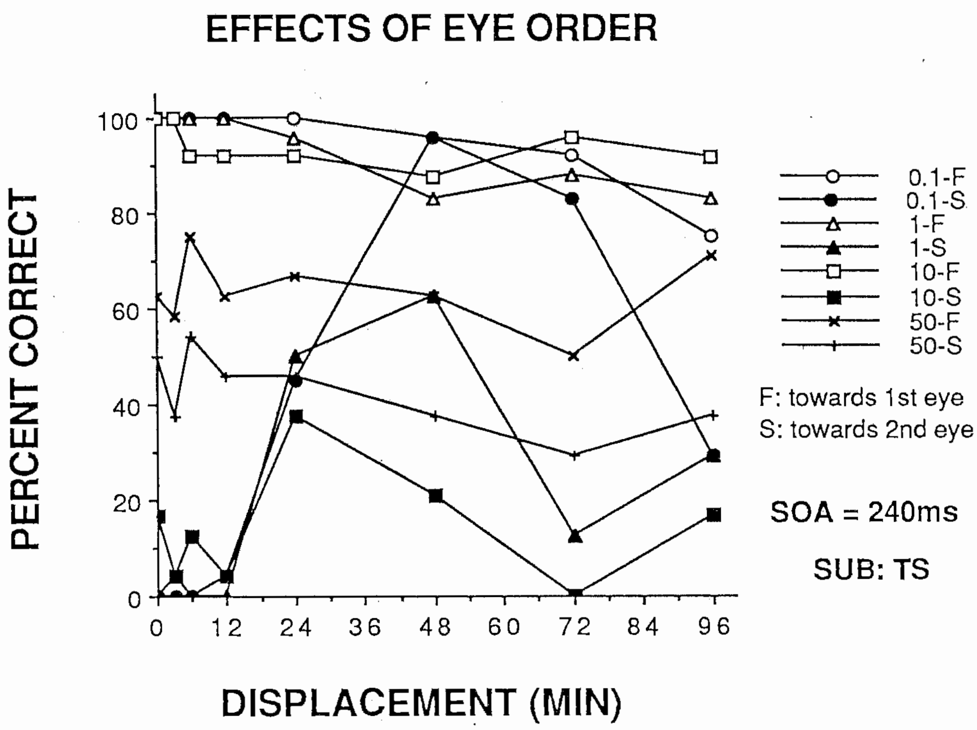

Fig. 6 Motion direction judgement according to eye-order in presentation.

EXPERIMENT III: FORCED DEPTH EXPERIMENT

The method of the forced depth experiment is similar to that for the previous experiment. The main differences are that the pattern has 3 x 3 deg target, and the subject was asked to judge depth direction(front/back) in all trials.

Stimulus

Display	66 Hz non-interlace CRT(Masscomp MC5600)
Dot size	3 min (white dots on black background)
Pattern size	6.4 x 6.4 deg (128 x 128 dots)
Target size	3 x 3 deg (60 x 60 dots)
Dot density	0.2, 1, 10, 50%
SOA	15, 30, 60, 120, 240 ms
Displacement	3, 6, 12, 24, 36, 48 min (1, 2, 4, 8, 12, 16 dots)

Results

The results are similar to those obtained in Experiment 1. The data from this forced-depth experiment clearly indicates that there is a clear upper SOA limit above which depth is not perceived. Stereopsis generally colapses when SOA exceeds 100 ms. Although the effect exists at all dot densities, the upper SOA limit is longer at higher dot-densities and shorter at lower dot-densities. Depth discrimination for 1% density pattern collapsed at 60 ms of SOA, whereas it does not disappear until 240 ms for 50 percent density pattern. That is, higher density is prefered by stereo system when the stimuli are presented sequentially. This is rather counterintuitive since higher density patterns should impose more processing load for the corresponding mechanism. The effect of dot density will be discussed in Experiment V.

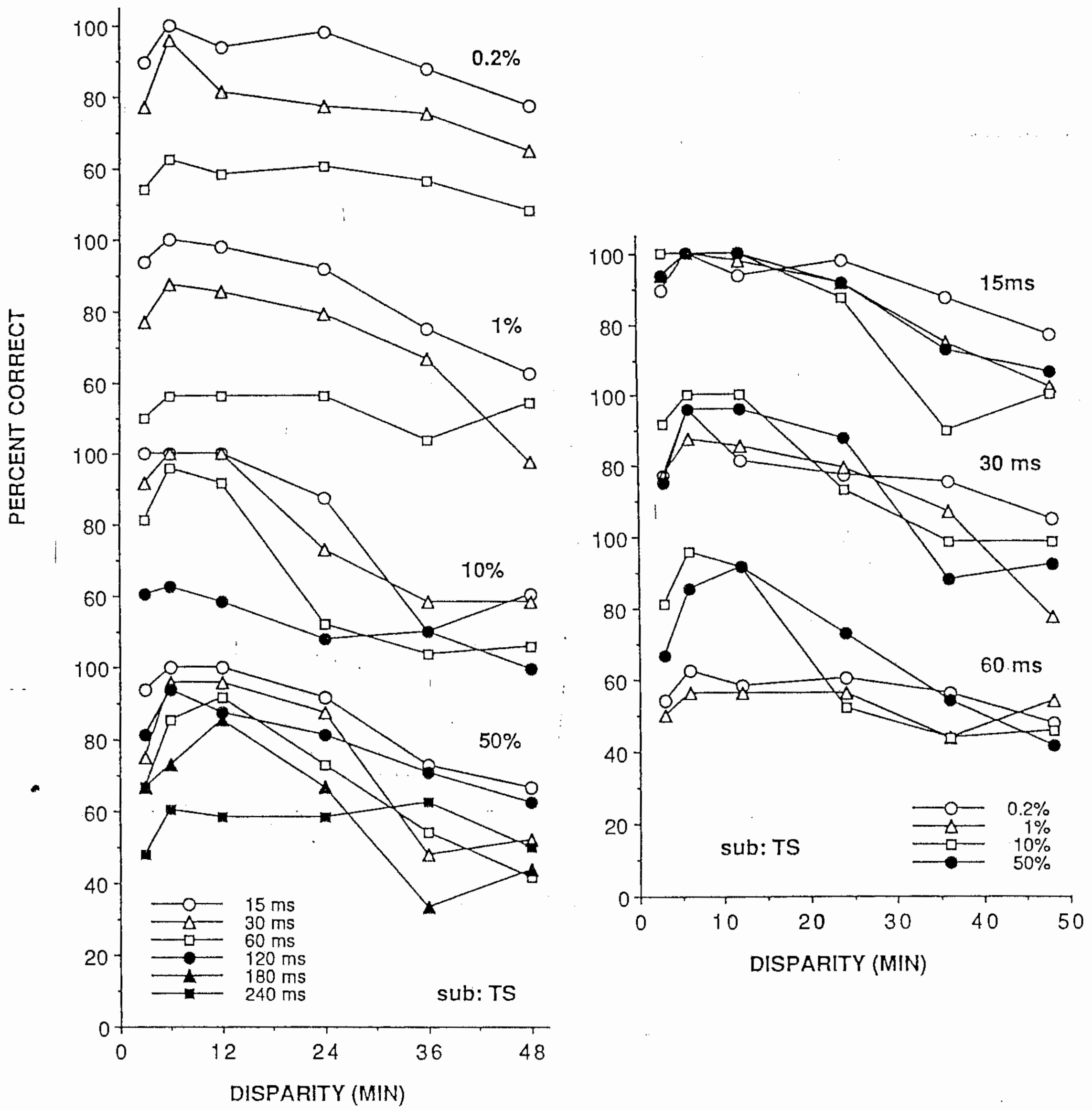

Fig. 7 Depth judgement in Experiment III.

EXPERIMENT IV: MONOCULAR MOTION EXPERIMENT

In experiment II, we assumed that lower dot-density favors the long-range motion mechanism and higher dot-density favors the short-range mechanism, and that the upper displacement limit should be larger at low dot densities. Although this is a quite logical inference, this has not really been confirmed experimentally. Past studies actually have reported conflicting results. Baker and Braddick(1982) reported that there is no effect of dot density, but Ramachandran and Anstis(1983) found larger displacements with patterns having low dot densities.

Another logical inference is that effects of SOA (Korte's third law) should emerge somewhere when we lower dot-density. This inference, again has not been demonstrated completely. Anstis and Ramachandran(1983) reported that the effect exists at very low dot density.

To examine if these hypotheses are true, an experiment in which dot-density and SOA for regular kinematograms was conducted. The method was the same as for Experiment II except that the subject viewed two patterns with the same eye.

Stimulus

Display	66 Hz non-interlace CRT(Masscomp MC5600)
Dot size	3 min (white dots on black background)
Pattern size	6.4 x 6.4 deg (128 x 128 dots)
Target size	None (Full field window motion)
Dot density	0.1, 1, 10, 50%
SOA	15, 30, 60, 120, 240 ms
Displacement	0, 3, 6, 12, 24, 48, 72, 96 min (0, 1, 2, 4, 8, 16, 24, 32 dots)

Results

The data is shown in Fig.8. There is an incontinuity in data between the lowest density(0.1%) and the other densities. The effect of dot density is clear in Fig. 7(left). The upper displacement limit is almost constant from 50% dot-density down to 1%, but becomes very large at 0.1%. The data clearly indicates that there is a qualitative differences between processing of motion information in low density and medium to high density regions, and suggests that there is a shift between the short-range-mechanism and the long-range mechanism..

The effect of SOA(Fig. 8, right) suggests the same conclusion. The data indicates that there is almost no effect of duration between 60 and 240ms for patterns of 1 to 50% density, but there is a clear widening of the upper displacement limit for 0.1% density patterns. That is, Korte's third law exists only at 0.1% density.

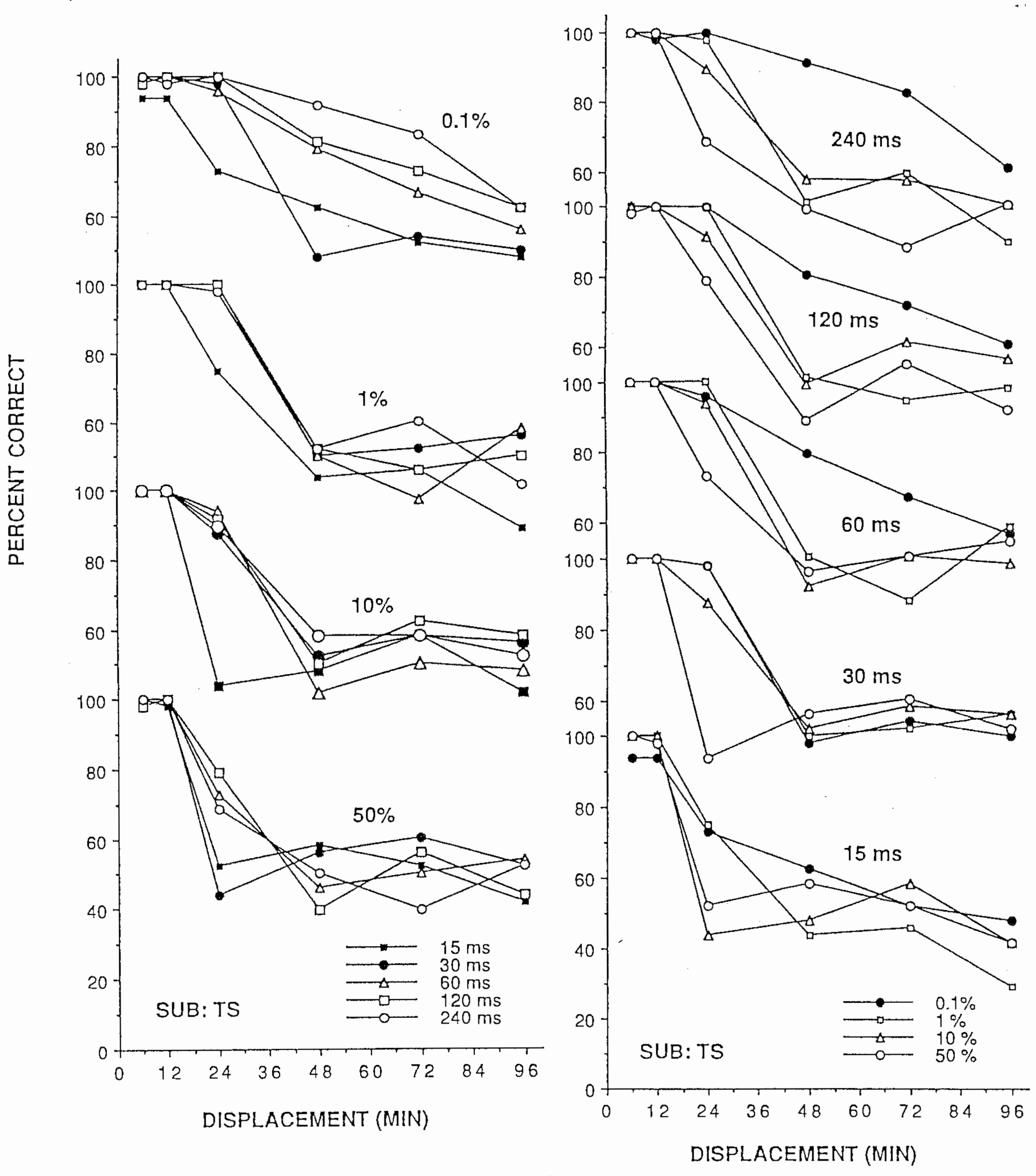

Fig. 8 Motion judgement in regular(monocular) kinematograms. The effect of dot density (left) and the effect of SOA(right).

EXPERIMENT V SIMULTANEOUS STEREOPSIS

The results of Experiment III suggest that the human stereo system can process patterns with higher densities more easily than those with lower dot densities. This may be only true when two patterns are presented sequentially, but it may also be true for stereopsis in general. To examine this point the effect of dot-density in regular random-dot stereograms are examined in this experiment. The method is almost exactly the same as for Experiment III, except that the two patterns are presented simultaneously in this experiment.

Stimulus

Display	66 Hz non-interlace CRT(Masscomp MC5600)
Dot size	3 min (white dots on black background)
Pattern size	6.4 x 6.4 deg (128 x 128 dots)
Target size	3 x 3 deg (60 x 60 dots)
Dot density	0.2, 1, 10, 50%
Duration	15, 30, 60, 120, 240 ms
SOA	0 ms
Displacement	3, 6, 12, 24, 36, 48 min (1, 2, 4, 8, 12, 16 dots)

Results

The results are shown in Fig9. The effect of dot-density, shown in Fig. 9 (left), indicates that at all durations the upper disparity limit is larger for lower dot densities. Therefore, the present data indicates that lower dot density favors the stereo system as long as the upper disparity limit is used as a measure. The preference for higher dot-density observed in Experiment III is probably limited when the two patterns are presented sequentially.

Although larger displacement(disparity) limits are found for lower dot-density for both motion and stereopsis, the effects are quite different. In motion(Fig. 8, left), there is little effect of dot-density between 50 and 1% densities, and the upper displacement limit becomes wider only at 0.1% density. In stereopsis, there is a gradual effect from 50% down to 0.1%(Fig. 9, left). There is a similar difference between the effect of SOA in motion and that of duration in stereopsis. For motion, the effect of duration is evident only with the lowest dot-density(Fig. 8, right). However, the effect can be seen at all dot-densities for stereopsis(Fig. 9, right). These results suggest that the motion and stereo mechanisms are based on quite different algorithms.

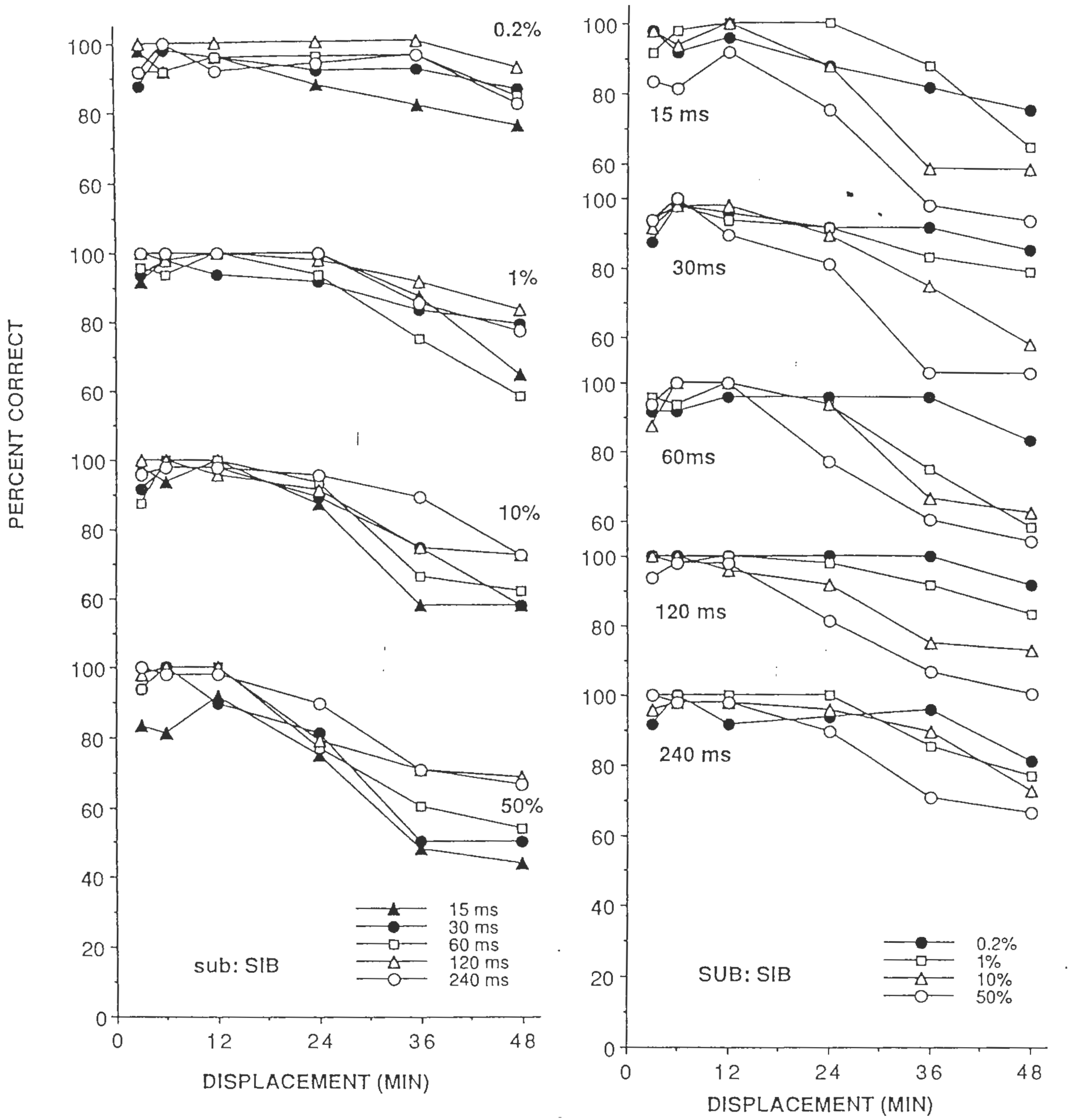

Fig. 9 Depth judgement in regular(simultaneous) stereograms.

The effect of dot density (left) and the effect of SOA(right).

CONCLUSIONS

1. Motion and depth perception under dichoptic and sequential presentations.
   Motion perception dominates when SOA is under about 100 ms, but motion perception prevails at longer SOA. The transition between motion and stereo occurs at a longer SOA as dot-density is increased.

2. Motion discrimination under D-S presentation.
   Motion direction discrimination is accurate only with very low dot-density, long SOA, and large displacement, i.e. in conditions favorable for the classical motion. In other conditions the accuracy is about 50%. The perceived direction depended almost completely on eye-order, i.e. the short-range motion mechanism does not seem to function under D-S presentation. Motion perception under D-S presentation is either eye-order-dependent motion or classical apparent motion.

3. Effect of dot-density and SOA on perception of random-dot motion.
   There is no effect of dot-density on the upper displacement limit between 1% and 50% dot-density. The effect becomes evident and the upper displacement limit becomes significantly wider only at the lowest dot-density(0.1%). Similarly, the effect of SOA(Korte's third law) becomes visible only at the lowest SOA.

4. Effect of dot-density on stereoscopic depth perception.
   In contrast to motion perception, there is a clear effects of dot density on upper disparity limit over the whole range of dot-density(0.2% - 50%). Similarly, the effect of SOA is evident at all dot-densities.

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