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Direction discrimination of apparent motion induced by color and shape : An implication to the temporal aspect of feature integration

Hiroshi YOSHIDA

ABSTRACT

In order to investigate the temporal aspect of feature integration process, correspondence strength in apparent motion induced by the multiple stimulus elements was measured, where each of stimuli was defined by color and shape. When the features in one dimension move leaving the other static (e.g., colors move but shapes are static), the motion correspondence can be found only at the modular level, but not at the higher level that consists of combined representations. In such conditions, varying frame duration, it was shown that the discrimination of motion direction got worse steeply from 71 to 142 ms duration. The results suggested that the representations with combined features became available at about 100 ms exposure, and the failure of matching stimuli at that level caused a noise signal to the motion mechanism. Additionally, an analysis of directional bias of perceived motion implied the existence of different correspondence mechanisms not only between short and long duration but also between color and shape.

INTRODUCTION

Every object in the real world usually has conjoined features, such as its location, color, shape, size and other physical properties. In our conscious perceptual experiences, these conjoined features seem to be perceived together, building up a whole entity of an object, and even more difficult to be aware of each elementary sensation. However, recent theories of visual object perception are concerned not only with these conscious experiences but also with pre-attentional part of visual information processing. For example, Marr (1982) suggested the advantage of modular analysis in an early stage of the process, where modules are specialized to the different visual properties of scenes. The idea of modularity is supported by a number of anatomical and physiological studies that discovered parallel organization of the visual system and neurons specialized to the different visual properties (Lennie, Trevarthen, van Essen, & Wässle, 1990).

Feature integration theory introduced by Treisman (Treisman & Gelade, 1980 ; Treisman, 1988) is also one of the models of visual processing that favors the idea of modularity in feature analysis. Although the theory is not fully specified but rather tentative, it has been discussed as an influential framework describing the process in visual object perception. In feature integration theory, the perceptual process is roughly divided into two stages. In the first stage, features in the different dimensions are initially coded independently, automatically and in parallel. Then, in the second stage, they are recombined under the focused attention to make a single representation of an object. Since the first stage here must precede the second stage, it would take a while until the recombined object representation in the second stage to be available.

The biggest question that will be under discussion in this study is quite simple, asking "How long does it take us to have a representation of object with combined features?"

A visual search paradigm has often been used to investigate the feature integration process. Although this paradigm shows clear differences between two stages of visual processing, it would not be appropriate for the purpose of this study, because the reaction time commonly used in the visual search experiments is a complex outcome of the various kinds of mental and motor processes. Instead of using such higher order indices, we might be able to use more primitive percept as an index of feature analysis.

When a stimulus presented at one location is alternated with the second stimulus at a different location, we see an apparent motion from the first to the second position (Wertheimer, 1912). Some investigators have suggested that the identical features between the first and second stimuli affect the strength of motion perception, in other words, strength of correspondence. For example, Berbaum, Lenel, & Rosenbaum (1981) have suggested that the shape identity influences the strength of correspondence in apparent motion. Similar contribution of object features to the motion correspondence have been investigated for orientation, size, spatial frequency, color and so on (e.g., Ullman, 1980; Mack, Klein, Hill, & Palumbo, 1989; Watson, 1986; Papathomas, Gorea, & Julesz, 1991). Although the apparent motion induced by feature correspondence does not seem to be so strong and sometimes failed to show the effect (Navon, 1976), it can be a powerful tool to study the spatio-temporal aspect of visual processing of multi-dimensional attributes (Papathomas & Gorea, 1988).

Going back to the feature integration now, the essential ideas of the present study will be introduced. Figure 1 shows the schematic views of stimuli where both color and shape induce motion correspondence (colors indicated by white, gray and black). In this figure, if the stimulus at the top-left is alternated with the one at the top-right (horizontal bi-directional arrow) without changing the position of the whole, the stimulus items appear to move to the right. Similarly, alternating the stimulus at the top-left with the one at the bottom-left (vertical bi-directional arrow) yields downward apparent motion. Another scheme at the bottom-right of Figure 1 shows what happens between the feature integration process and motion mechanism, where arrows accompanied by "+" indicate the motion signals from perceptual units to a motion mechanism. In this case, both color (C) and shape (S) would contribute to the motion correspondence. Additionally, the combined representations of the stimulus objects (OBJ), as well as individual features, could stimulate motion mechanism (for example, see a "gray circle" still at the neighboring location after alternation).

In Figure 2, three cases in which color provides the motion correspondence are shown. Note that the colors are exactly aligned to move in all of these stimulus settings. First, in Figure 2 A, all the shapes are identical (square). Consequently, it is obvious that the shape module does not contribute to the perception of apparent motion. What happens when color and shape features are combined at higher level in this case? Even at the level of combined features, each color still seems to stick onto the same square (see a "gray square" is still at the neighboring location as a "gray square" without changing any of features, as if the shape moved together with the color). So, in such case, combined features might also produce the motion correspondence.

In the second case, however, this higher level

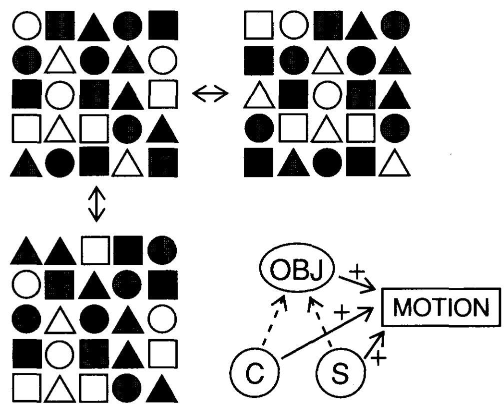

Figure 1. A scheme of the apparent motion stimuli in which both color and shape move. "C" and "S" represent color and shape modules respectively, whereas "OBJ" represents combined representations. Solid arrows accompanied by "+"s indicate the motion signals, and dashed ones indicate the streams of perceptual process.

seems to work in a different way because shapes are various and static. As seen in Figure 2 B, a "gray square" is no longer a "square" at the expected location, and you may see another "gray square" accidentally appeared elsewhere. Therefore, if the combined representations contribute to the motion correspondence, the failures of correspondence seem to generate motion noises (indicated by the arrow accompanied by "−" in Figure 2 B). Additionally, the stimulus setting might have the shape module work a little differently. Since shapes are obviously static in this case, the shape module at an early stage might give a static signal to the motion mechanism (indicated by the arrow with "0").

The third case, shown in Figure 2 C, was designed to give the noise signal at an early stage. In this case, the shapes are alternated with another matrix of randomly aligned shapes, while colors are left in motion. Here, not only the combined representations but also the shape module would produce the noise. So, it is expected that the perception of apparent motion becomes difficult even in an early stage of perceptual process, because the noise from the shape module would directly conflict with the correspondence

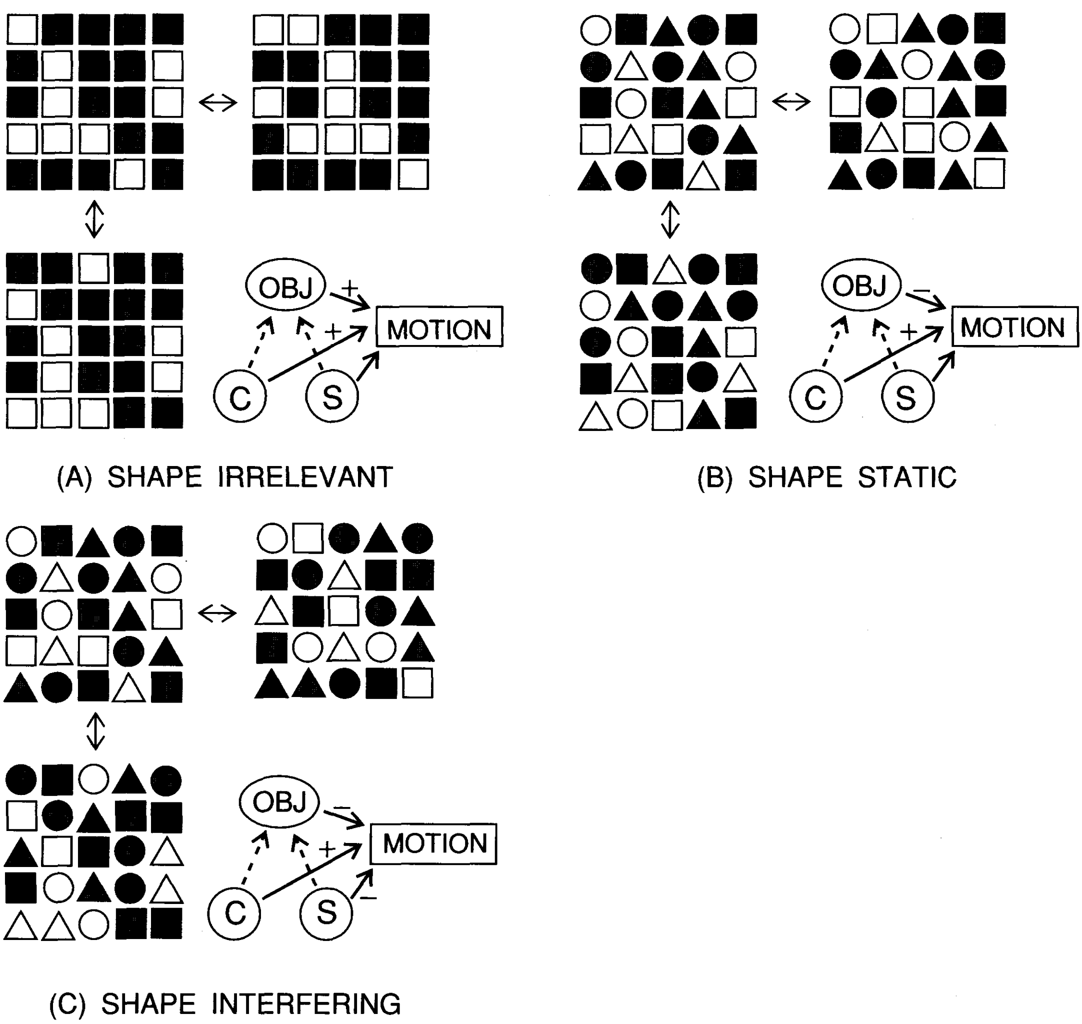

Figure 2. Three settings of the apparent motion stimuli in which color induces correspondence. In the schemes of models, "+"s, "0"s and "−"s accompanying the solid arrows indicate the motion, static and noise signals, respectively.

induced by color module.

In the present study, the correspondence strength of apparent motion is measured under several conditions, such as the ones shown above. Varying the frame duration of the stimulus display, the relationships among those conditions are expected to tell us about the spatio-temporal aspects of feature integration process.

METHOD

Subjects

Fifteen adult subjects participated in the experiment. All of them had normal or corrected-to-normal visual acuity and normal color vision.

Apparatus and stimuli

A microcomputer (NEC PC-H 98 model U 100) and a color CRT monitor (NEC PC-KD 853 n; 56.4 Hz frame rate) were used for stimulus presentation and encoding of the subjects' responses. Although the stimulus display schematically shown in Figures 1 and 2 consisted of a 5 × 5 array of stimulus items, a 25 × 25 large array was actually used, which subtended 15 deg in visual angle from the viewing distance of 57 cm. A chin-rest was used to keep the viewing distance constant. Each stimulus item had one of three shapes (circle, triangle or square; all filled) and one of three colors (red, green or blue). Shapes were obtained from the symbol font set of the computer, which consisted of 16 × 16 pixels dot matrices, each subtending 0.6 deg visual angle. The CIE x, y coordinates of three colors were 0.605, 0.367 for red; 0.317, 0.578 for green; and 0.143, 0.075 for blue (measured by Minolta CS-100 color analyzer). The luminance levels were 2.3, 9.9 and 1.6 cd/m^2, respectively. It should be noticed that these colors were not equiluminant, so that the word, "color," in the present study, means not only a chromaticity but also an achromatic luminance.

In order to produce the feature induced apparent motion, two stimuli were alternated back and forth, so that the oscillating movement was seen. In one of the stimuli, the colors and shapes of the items were randomly chosen. In the other, both or either of features were displaced horizontally or vertically. The displacement size of items was always two across columns (horizontal motion) or two across rows (vertical motion) moving 1.2 deg in terms of visual angle, though it was shown as one in Figures 1 and 2 for simplification.

Procedure

The subjects' task was to judge the direction of apparent motion (horizontal or vertical) in a two-alternative forced choice paradigm, in which no feedback was given. The frame duration of motion display was varied. The values were 18, 35, 71, 142, 284 and 567 ms. ISI was always zero. The color and shape were manipulated differently in the following stimulus conditions.

Both in motion. As seen in Figure 1, both color and shape were moved together. In this condition, both color and shape modules can provide the motion mechanism with correspondence. Additionally, the combined representations would also contribute to the motion correspondence. No conflict is expected between the motion correspondences from these three sources.

Color in motion. Three sub-conditions, in which color module contributes to the motion correspondence while shape has different role, were designed.

(a) *Shape Irrelevant.* All the stimulus items were uniform in shape, so that the shape module does not contribute motion correspondence by itself. In this condition, note that the correspondence from combined representations does not seem to interfere the one from the color module (Figure 2 A).

(b) *Shape Static.* Shapes were various and static. Since only colors move leaving shapes behind, the higher level of combined representations would fail to match the stimulus items (Figure 2 B). Accordingly, the noise from combined representations seems to interfere the perception of motion. However, if the stimulus exposure were too short to have such representations, the noise might not work. Therefore, the noise from combined representations would need longer frame duration to become effective.

(c) *Shape Interfering.* Shapes were alternated with another matrix of randomly chosen shapes (Figure 2 C). In this condition, shape module would also give a noise to the motion mechanism. Such a noise seems to conflict with the motion signal from color module even if the frame duration is short.

Shape in motion. Contrary to the conditions described above, stimuli were arranged to have the shape module contribute to the motion correspondence in the following conditions. Since these conditions were the inverse case of color-in-motion conditions, similar interactions were hypothetically expected.

(a) *Color Irrelevant.* All the stimulus items were identical in color, while shapes were various and aligned to show the apparent motion.

(b) *Color Static.* Colors were various and static.

(c) *Color Interfering.* Colors were alternated with another matrix of randomly aligned colors.

RESULTS

Each subject ran 20 trials each for seven stimulus conditions and six levels of duration, so that totally 840 trials were given. The results are shown in Figure 3 for color-in-motion condition, and in Figure 4 for shape-in-motion condition. The results from both-in-motion condition are shown in a dashed line in those figures.

Both in motion. When both color and shape moved cooperatively, probability of correct discrimination of the motion direction was relatively high. Even at the shortest frame duration (18 ms), apparent motion was correctly perceived at the rate of 0.85. Then it increased to the satisfactory level at 35 ms duration and stayed high also for longer duration (> 0.9). An ANOVA on the frame duration, using angular values of probabilities, showed significant main effect ($F(5,70) = 10.68$, $p < .001$). According to the subsequent comparisons by Ryan's method ($p < .05$), significant increase of probability was found between 18 and 35 ms frame duration.

Color in motion. When only color moved, perception of apparent motion differed across the conditions in which shape had different roles. A 2-factorial ANOVA on four stimulus conditions (shape-irrelevant, shape-static, shape-interfering and both-in-motion) and six levels of duration showed that the main effects of conditions ($F(3,42) = 53.39$, $p < .001$) and duration ($F(5,70) = 13.71$, $p < .001$) were both significant. Additionally, an interaction between them was marginally significant ($F(15,210) = 1.53$, $p < .10$). So the paired comparisons were applied to describe the results more in detail.

(a) *Shape Irrelevant.* As seen in Figure 3, if shapes were uniform and irrelevant to the motion correspondence, color induced apparent motion quite well. In fact, no matter how long the frame duration was, there were no significant differences between this and both-in-motion conditions. In this condition, similarly to the both-in-motion condition, significant differences were seen between 18 ms and all other levels of frame duration.

(b) *Shape Static.* In the short exposures (less than or equal to 71 ms), probability of correct perception of motion direction increased as the frame duration was prolonged. However, extending frame duration to 142 ms yielded the significant loss in the apparent motion perception (.92 to .83 ; Figure 3). In

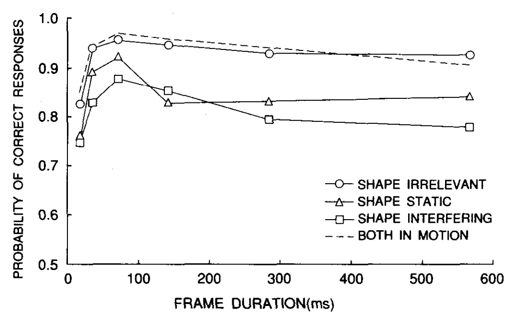

Figure 3. Probabilities of correct responses in color-in-motion condition. (Dashed line shows the result of both-in-motion condition in this and subsequent figures.)

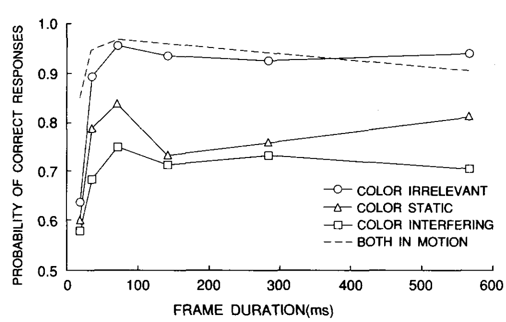

Figure 4. Probabilities of correct responses in shape-in-motion condition.

comparison with shape-irrelevant condition, probability of correct motion perception significantly declined at 18, 142, 284 and 567 ms. The differences at 35 and 71 ms frame duration were not significant.

(c) *Shape Interfering.* When shape induced motion noise, perceiving correct motion direction was generally difficult. In comparison with shape-irrelevant condition, significant differences were shown across all frame duration. Unlike in shape-static condition, moreover, the steep reduction of motion detection was not observed.

Shape in motion. Another 2-factorial ANOVA on four stimulus conditions (color-irrelevant, color-static, color-interfering and both-in-motion) and six levels of frame duration showed significant main effects of conditions ($F(3,42) = 109.64$, $p < .001$) and duration ($F(5,70) = 33.39$, $p < .001$). An interaction between these variables was also significant ($F(15,210) = 4.90$, $p < .001$).

(a) *Color Irrelevant.* When colors were uniform and irrelevant to the motion correspondence, the perception of apparent motion improved remarkably as frame duration increases from 18 to 71 ms. Paired comparisons showed significant differences in probabilities between 18 ms and all other frame duration. Although the probabilities at 18 and 35 ms were lower than those in both-in-motion condition, no significant differences were shown at longer duration.

(b) *Color Static.* When colors were various and static, probabilities of correct detection of motion direction were significantly lower than color-irrelevant conditions except for 18 ms frame duration. More importantly, as seen in the shape-static condition described above, a significant reduction in the direction discrimination was seen between 71 and 142 ms frame duration (0.84 to 0.73 ; Figure 4).

(c) *Color interfering.* Similarly to shape-interfering condition, the detection ratios of apparent motion were generally reduced when color induced motion noise.

DISCUSSION

In this study, the experiment was designed to investigate the feature analysis in perceptual processing using correspondence strength in apparent motion as an index. If the combined features contribute to the motion correspondence, failure of matching stimulus elements is expected to interfere the motion perception when one of the features moves but the other is static (like one shown in Figures 2 B). If so, the effectiveness of the interference might vary as a function of frame duration, because the representations with combined features would not be available when the exposure is too short to reconstruct them.

The results do seem to show the existence of such combined representations contributing to the motion correspondence. In both color-in-motion and shape-in-motion conditions, the detection ratios of the apparent motion have dropped steeply between 71 and 142 ms frame duration only when another feature is static. It is considered that the failure of matching at the level of combined representations brought a noise signal to the motion mechanism, consequently causing the difficulty of direction discrimination. Of course, there were other sources of information that might weaken the perception of apparent motion. Since the features not in motion were obviously static in these conditions, they might provide the motion mechanism with static information. Such information from lower modules, however, should work at an earlier stage. Actually, the results from additional conditions, in which one of the features elicited the interfering motion noise at the modular level, showed that the noise brought difficulty to the motion perception consistently from short duration. Therefore, the drop in detection ratio in the static condition does not seem to be due to the information from lower modules. The motion noise from higher level rather than the modules seems to account for these steep reductions of motion perception more suitably. Therefore, it can be considered that it takes about 100 ms for the perceptual process to have a combined representation with multiple features.

Although the overall profiles of interactions among three sub-conditions look similar between color- and shape-in-motion conditions, there still seem to be a few differences. First, color information contributed to the motion correspondence even at the shortest duration (18 ms), while the detection ratios of motion from shape were near the chance level. Second, the differences among three sub-conditions were apparently greater in shape-in-motion condition than in color-in-motion condition. In other words, the color affected the motion correspondence from shape more than the shape did on the color. Three colors, red, green and blue, used in the experiment were not equiluminant, so that the luminance module could also be driven by the color information. Such luminance information, which is brought by the low spatial frequency components, is known as quite influential in motion perception (e.g., Ramachandran, Ginsburg, & Anstis, 1983). It can be considered that the luminance induced a strong correspondence in the present experiment, while shape information, brought by the relatively high spatial frequencies, was weaker.

In terms of luminance, one may think of that the shapes might affect the luminance module as well, because the shapes are obtained from the font set of the

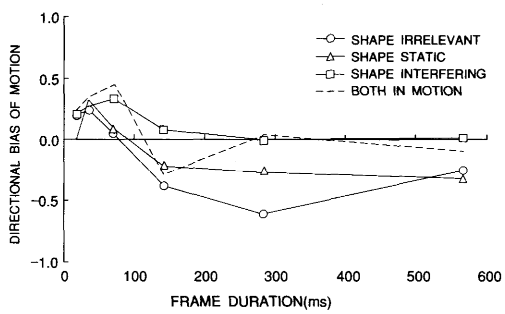

Figure 5. Directional biases (log beta) in color-in-motion condition. Positive values indicate biases toward vertical direction, and the negatives indicate the ones toward horizontal direction.

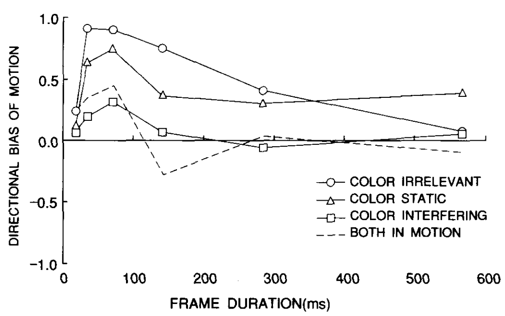

Figure 6. Directional biases (log beta) in shape-in-motion condition. Positives indicate vertical directional biases.

computer so that the areas of them were not controlled exactly. The dark area of background might be larger between adjoining triangles than squares. If so, the results might not reveal the interaction between color and shape modules but rather the interaction within the luminance module. Are there multiple modules behind the present results? Attempting to answer this question, the data were analyzed from a different point of view.

Figures 5 and 6 show the directional biases of subjects' responses in color- and shape-in-motion conditions respectively. Those values are the beta weights calculated by means of the signal detection theory. Since the data that have hit rates of 1.0 do not fit this theory, the pooled data across all subjects were used tentatively. So the analysis here should be regarded as arbitrary. However, the analysis of the directional bias showed quite noticeable tendency of the result. In color-in-motion condition, there seem to be relatively small biases toward the vertical direction at the short duration (less than or equal to 35 ms), and switch to the horizontal direction after 142 ms when shapes are irrelevant or static. On the contrary, consistent vertical biases are seen in shape-in-motion condition. When both color and shape move, no matter which they generate motion signal or noise, such biases seem to disappear when frame duration exceeded about 100 ms. However, if the feature on the one hand is irrelevant or static, the directional biases seem to remain for vertical direction when shape moves, and for horizontal direction when color moves.

Directional bias toward vertical motion, called "vertical anisotropy," has often been observed in directionally ambiguous motion stimulus (e.g., Navon, 1976). And it is attributed to the fact that vertically displaced elements stimulate same hemisphere, whereas horizontally displaced ones stimulate opposite hemispheres (Gengerelli, 1948). What caused the "horizontal" anisotropy? Are there any anatomical correlations to the horizontal meridian dividing the visual field? One may think of the differences between the areas V 3 and VP in the visual cortex, where V 3 corresponds to the lower visual field and VP corresponds to the upper visual field (Lennie et al., 1990), and they are functionally different in the processing of color information. Of course, inference of such anatomical correlations might be too radical to discuss in this study. Further studies are necessary to investigate the directional preference of feature induced motion perception more in detail. However, the different directional biases shown here seem to suggest the existence of different mechanisms for color and shape information.

The present study may also give rise to several problems in regard to the theoretical issues suggested by the earlier studies. Although the data obtained in the present experiment may not be enough to answer these problems, it seems valuable to discuss here to clarify the concerns to the underlying functional mechanisms.

First, in feature integration theory, Treisman discussed that the visual attention is necessary to have a temporal representation with combined features (Treisman & Gelade, 1980). Features in different dimensions can be accessed simultaneously only within the attentional spot light. Was the attention needed to perceive the apparent motion in the present experiment? In the studies of apparent motion, it has been shown that the subjective factors, such as previous experiences or attitudes, affect the motion perception (e.g., Kolers, 1972). But it is not clear yet how "attention" contributes to the solution of correspondence problem in the various feature dimensions. Systematically controlling attention will be necessary in the further studies.

The second problem is concerned with the dichotomy of apparent motion perception. Many of recent researchers on apparent motion have discussed the existence of two motion mechanisms (e.g., Braddick, 1974; Petersik, 1989). One of them, often called "short-range" process, works in the short spatio-temporal range of stimulus conditions and does not care much about the stimulus features. And the other, called "long-range" process, works more slowly and preferably relies on the feature correspondence. The size of displacement used in the present experiment (1.2 deg) exceeded the displacement limit of short-range process, so that the interaction was assumed to take place in the long-range process. However, the directional biases obtained in the experiment imply the different mechanisms contributing to the perception of apparent motion. In short duration, the directional biases were found in vertical direction both for the color- and shape-in-motion. But they were observed in the different directions for the longer duration. The fact seems to suggest the existence of different mechanisms working not only for color and shape but also for the short and long exposed stimulus. Therefore, it would be important to consider the multiple levels of visual representation not only in terms of feature analysis but also in terms of the correspondence process for more detailed investigation.

The problems shown above seem to make the functional relationship between feature analysis and correspondence process much more complex. It would not be easy to seek the answers to those. Besides, the timing of feature integration suggested in this study would not be the absolute index. It can be investigated under many combinations of other feature dimensions, and the timing may vary depending on many factors, such as intensities of features or size of displacement. However, investigating such a relationship still sounds important beyond these problems, because our perceptual experiences extend not only in space but also over time. The methodology introduced in the present study seems to be one of the effective tools for such aim.

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(コミュニケーション学科)

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