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The Influence of Velocity on the Detection and Prediction of Changes in Color and Motion Direction

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Abstract: The present study examined the degree to which the perception of change in motion direction is delayed, compared with that in color, depending on the motion velocity, by using detection and prediction tasks. In Experiment 1, stimulus patterns abruptly reversed color and changed their direction of motion synchronously, and observers were asked to respond when they perceived the reversal of a particular attribute. The detection times for changes in color were 60–70 ms shorter than those for changes in motion direction of the same patterns. Further, the detection times decreased with the velocity of pattern motion, except for the stationary pattern. In Experiment 2, after the color and motion direction of the test patterns changed synchronously and then disappeared, observers were asked to predict the temporal period of one change cycle. The predicted times for the change in color were shorter than those for the change in motion direction. The predicted times increased with the velocity of pattern motion. The relationship between the influences of velocity and perceptual asynchrony are discussed.

Keywords: *detection of change; prediction of change; perceptual asynchrony; velocity influences*

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1. Introduction

In studies of neurophysiology, it has been proposed that the attributes of color and motion are processed in different places in the brains of primates (Livingstone & Hubel, 1988; Zeki, 1978) and that each place is functionally specialized (Livingstone & Hubel, 1987). It is said that the response latencies to the stimulus onset of MT cells specific to motion information processing are shorter than those of V4 cells specific to color information processing (Buchner, Weyen, Frackowiak, Romaya, & Zeki, 1994; Ffytche, Guy, & Zeki, 1995). Similar evidence has also been found in psychophysical studies. For example, color-contrast flicker fusion occurs at much lower frequencies than luminance-contrast flicker fusion (Livingstone & Hubel, 1987). Equiluminous motion gratings are perceived to be slower than luminous gratings (Cavanagh,

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Tyler, & Favreau, 1984), motion aftereffects of equiluminous gratings do not occur clearly (Mullen & Baker, 1985), and apparent motion by equiluminous gratings does not occur (Ramachandran & Gregory, 1978). These findings indicate that responses in the motion system are faster than those in the color system.

However, recent psychophysical studies have offered the opposite results, which indicate that motion perception is slower than color perception. Moutoussis and Zeki (1997) presented observers with periodic changes in the color and motion direction of dot patterns on a computer screen and asked them which color corresponded to which motion direction. The results showed that even when changes in color and motion direction occur simultaneously, the change in color is perceived nearly 80 ms before the change in motion direction. Arnold and Clifford (2002) reported that the maximum temporal delay occurred when they used opposite pairs in motion direction and that the delay decreased with successive decrements in the angle of difference between two motion directions. Bedell, Chung, Ogmen, and Patel (2003) compared the 'color coincidence task', in which observers judged the color when dots moved in a specific direction, with the 'temporal order judgment (TOJ) task', in which observers judged whether motion change took place before or after color change. In the color coincidence task, the asynchrony between changes in color and motion depended on the difference in the angle between two motion directions; in the TOJ task, however, the delay was small and not dependent on the angle between directions or on the motion velocity.

Moutoussis and Zeki (1997) suggested that perceptual asynchrony reflects the result of processing in two distinct systems and that color and motion are perceived independently of one another. Arnold, Clifford, and Wenderoth (2001) reached a similar conclusion based on the experimental results of color-contingent motion aftereffects. They concluded that if the time course of perceptual experience in this phenomenon correlates directly with that of neural activity, then differences in stimuli that affect specific neural systems would be directly reflected in perception. On the other hand, Nishida and Johnston (2002) concluded from their study that the time taken for the brain to represent color change is the same as that to represent direction change but that the visual system has separate mechanisms for temporal judgments, and thus they raised objections to the view of Arnold et al., after comparing the results of various tasks. According to their results, asynchrony occurs only when the temporal period is short and the direction of motion is rapidly changed, and this is produced by a matching mistake that depends on the difference in the temporal structures of the stimuli between transitions (first order change) and turning points (second order change). Recently, Bartels and Zeki (2006) showed that the time required to bind two colors is longer than that required to bind two motions and that the time required to bind color to motion is the longest. They concluded that spatial binding is separate from and subsequent to stimulus processing and that it is an attribute-dependent and post-conscious process. This conclusion approximates that of Nishida and Johnston (2002), but the argument has yet to be settled because we still do not know whether the time taken for the brain to represent color change is the same as that to represent direction change.

Previous studies have examined the influences of the angle between two directions, motion velocity, and temporal period on perceptual asynchrony. The present study deals with one of these aspects: the influence of motion velocity on perceptual asynchrony. It is said that the magnitude of temporal delay in this phenomenon depends on the temporal period (Moutoussis & Zeki, 1997; Nishida & Johnston, 2002) but does not depend on the motion velocity (Aymoz & Viviani, 2004; Bedell et al., 2003). However, studies that measured response times in motion perception have shown that the response times to changes in motion direction decrease as velocity increases (Hohnsbein & Mateeff, 1998; Mateeff, Dimitrov, & Hohnsbein, 1995; Mateeff & Genova, 2005; Tynan & Sekuler, 1982). Moreover, studies of time perception have shown that perceived duration for fast-moving stimuli is longer than that for slow-moving stimuli (Brown, 1995; Lhamon & Goldstone, 1975; Mashour, 1964; Rachlin, 1966; Tayama, 1987; Tayama, Nakamura, & Aiba, 1987). The influence of velocity has been clearly observed in these studies, but its influence on perceptual asynchrony has yet to be reported with the exception of a recent study by Kreegipuu, Murd and Allik (2006), even though similar stimuli and paradigms have been used. Thus, the lack of evidence on the influence of velocity is one of the inexplicable and interesting facts related to perceptual asynchrony. The reason for this might simply be that the influences of velocity, and especially of slow velocities, have not been examined sufficiently, or that as asynchrony has heretofore been found to occur only with periodicity, the influence of velocity might not be found in events with periodic changes. Therefore, we thought that the influence of velocity should be examined more sufficiently, as such an examination might lead important findings related to the principles of perceptual asynchrony.

Temporal judgments are usually more difficult to make than spatial judgments. In studies of time perception, different experimental methods have yielded a number of opposing results (Allan, 1979; Zelkind & Sprug, 1974). In studies of asynchrony, observers have been asked to make a variety of judgments, including the direction of motion of test patterns when the patterns were a specific color, the color when test patterns moved in a specific direction, the temporal order of color and motion, and whether changes of color and motion were simultaneous. These are not easy judgments. Consequently, the results might have been influenced by various methods and conditions or by observer proficiency. To circumvent such problems, a detection task is often used to measure response times, as it is an easy task to perform. Nishida and Johnston (2002) have used such a task to examine asynchrony, but their findings indicated that perceptual asynchrony between color and motion could not be found. Barbur, Wolf, and Lennie (1998) have measured response times and showed that it took more time to detect the onset of coherent motion than to detect a change in color. More recently, Kreegipuu, et al. (2006) examined the time needed to detect changes in the color of a moving stimulus and showed that response times to detect changes in color decreased with velocity. This result indicates that color coding mechanisms do not act independent of the movement parameter and is therefore not in agreement with the results of Bedell, et al. (2003), who found no influence of velocity. Since these results were not necessarily consistent, in this study we decided to adopt a similar task to examine responses to changes in color and motion and the influence of velocity on perceptual asynchrony.

As previous studies have shown asynchrony to occur only with periodicity, if the motion velocity is irrelevant to perception of events with periodic changes, then we will not be able to find the influence of velocity in events with periodic changes. Accordingly, the present study also adopts a prediction task in addition to a detection task in order to examine events with periodic changes. In the prediction task, periodic changes in the attribute (color or motion direction) are shown to the observer, and then the stimulus disappears, at which point the observer then predicts the length of time for one cycle of change to occur in the attribute. This task is similar to the reproduction method used in previous studies of time perception in which the observer is asked to respond accurately rather than quickly, unlike the detection task. However, this task differs from the simple reproduction method, since the time is predicted while experiencing periodicity. As a result, processes related to perceptual asynchrony might be illuminated more strongly in the prediction task than in the detection task.

Thus, the present study aims at examining the difference between responses to changes in color and motion and the influence of velocity on perceptual asynchrony by using both detection and prediction tasks. Although the present study is akin to the recent study by Kreegipuu, et al. (2006), there are still some differences between the two studies. First, they dealt with the detection of changes in color but not with that in motion. They also did not deal with events with periodic changes, although their study was prompted by studies of perceptual asynchrony. Our study, on the other hand, does deal with these issues. Moreover, we use pattern motions as stimuli, while they used object motions. The following experiments were carried out to compare responses in the detection and prediction tasks and to examine the influence of motion velocity on the asynchrony between changes in color and motion direction. The two colors of red and green were used for the color changes, and upward and downward motions were used for the motion changes.

2. Experiment 1

This experiment examined whether there was a difference in the detection of changes between observers attending to color or to motion when the test patterns moved in a vertical direction. Changes in color and motion direction occurred abruptly and simultaneously.

2.1. Method

2.1.1. Observers

Six undergraduate students participated in the experiment. All had normal visual acuity, either uncorrected or corrected-to-normal.

2.1.2. Stimuli and apparatus

The stimuli were displayed on a 17-inch monitor (Nanao, FlexScan E55D) controlled by a Power Macintosh 8500/180 with a CPU accelerator board (Buffalo G4, 400 MHz). The refresh rate of the monitor was 75 Hz. A plus sign (+) of 3.5 x 3.5 mm was initially presented at a fixation point in the center of the monitor. Test patterns were presented in a stationary rectangular field (47 x 47 mm) and the center of the field was designated as the fixation point. A plaid test pattern was composed of two sinusoidal gratings with a spatial frequency of 1 c/deg and contrast of 80%. Each grating was oriented +45 degrees and −45 degrees from vertical (see Figure 1 (a) (b)). The test pattern moved in a vertical direction at uniform velocity, and after a random amount of time had passed, the color and motion direction were changed abruptly and simultaneously. The color was changed from red to green, or vice versa. Achromatic plaid was also used in some conditions. As for the direction, it was changed from downward to upward, or vice versa. Then, when the observer clicked the mouse, the test pattern disappeared. The average luminance of the test pattern and the background field was 10 cd/m². The CIE chromaticity coordinates (1931) were x = 0.337 and y = 0.325 for gray, x = 0.276 and y = 0.600 for red, and x = 0.633 and y = 0.333 for green. The observation distance was 54.6 cm. The experiment was conducted in a darkroom.

2.1.3. Tasks and stimulus conditions

Two kinds of task (color and motion), and three kinds of condition (color order, motion order, and velocity) were used. In the color task, there were two kinds of color order (red to green, and green to red), three kinds of motion order (stationary, upward to downward, and downward to upward), and four kinds of velocity (0, 1, 4, and 16 deg/s). Because the stationary condition in the motion order overlapped the velocity condition of 0 deg/s, there was a total of 14 conditions. In the motion task, there were three kinds of color order (achromatic color, red to green, and green to red), two kinds of motion order (upward to downward, and downward to upward), and three kinds of velocities (1, 4, and 16 deg/s). Here, achromatic color refers to gray-scale color. In this condition, only the motion direction changes and not the color. In total, there were 18 conditions.

2.1.4. Procedure

At the start of each trial, the fixation point with a plus sign and a beep sound were shown.

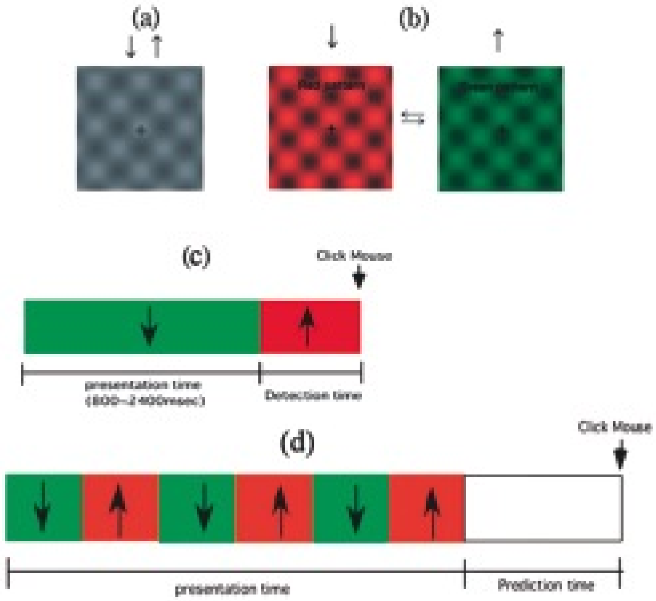

Fig. 1 Examples of stimuli used in the present study.

(a): Achromatic plaid. (b): Chromatic plaid (red and green plaids are alternately presented in the same position). The figure shows only the case where the test pattern moves downward in red plaid and upward in green plaid. Temporal flows in Experiment 1 (c) and Experiment 2 (d) are also illustrated.

The observer clicked the mouse and, one second later, a test pattern was presented at the fixation point. After a random length of time, ranging from 800 to 2400 ms, the color and the motion direction of the test pattern were abruptly and simultaneously changed. The shortest time (800 ms) is thought to be sufficient for the detection of changes in direction, as one of the authors has previously observed the minimum temporal threshold (T_{min}) for discriminating motion direction to be less than 100 ms for a stimulus of 1 deg/s (Tayama, 2000) and the time needed to perceive motion velocity as a constant to be about 250 ms for the similar stimulus (Tayama, 2004). In the color task, the observer was asked to ignore the change in motion direction while paying attention to the color, and then to click the mouse as quickly as possible when a color change was detected. In the motion task, the observer was asked to ignore the change in color while paying attention to the motion direction, and then to click the mouse when a change in motion direction was detected (see Figure1 (c)) . In both tasks, the test pattern disappeared when the mouse was clicked, and one second later, the fixation point was shown again with the beep sound, and the procedure was repeated. The time from the actual stimulus change to the mouse click was measured as the detection time for each trial. Each observer completed 10 randomly repeated trials for each condition in each task.

2.2. Results and Discussion

The mean detection time for each condition in each task was calculated. The mean detection times were 313.78 ms and 389.36 ms for the color task and motion task, respectively, and the difference was 75.58 ms. Detection times in the color task were clearly shorter than those in the motion task. Figures 2 (a) and 2 (b) show the results for the color and motion tasks, respectively. The horizontal axes in both figures indicate the velocity conditions, and the vertical axes indicate the detection times. In Figures 2 (b), the results for the chromatic and achromatic conditions are shown separately.

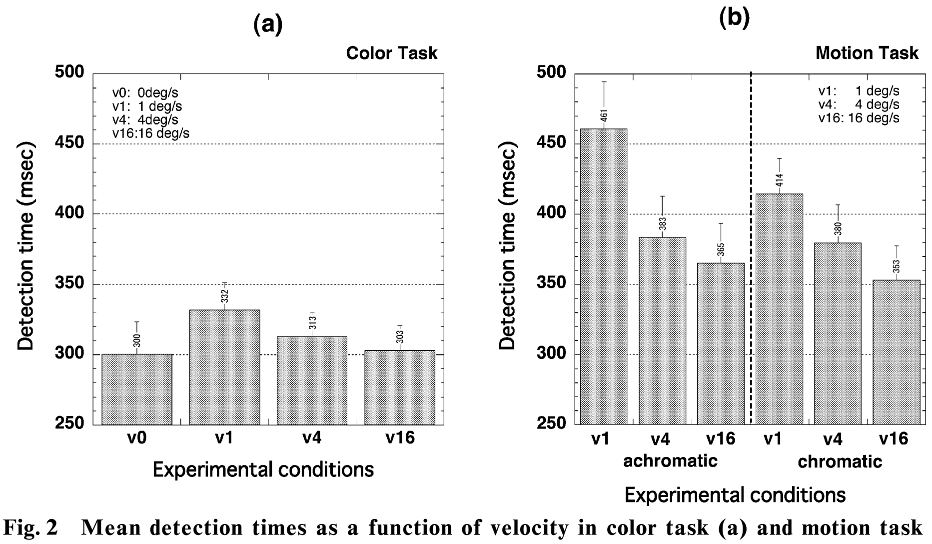

Fig. 2 Mean detection times as a function of velocity in color task (a) and motion task (b).
In the motion task, the results for chromatic and achromatic conditions are shown separately. Velocity conditions: v0 (deg/s), v1 (1 deg/s), v4 (4 deg/s), and v16 (16 deg/s). Error bar indicates standard error.

For the color task, an analysis of variance of three factors (color order, motion order, and velocity) was performed, based on the mean detection time for each condition in each observer. Only the main effect of velocity was significant ($F(3, 15) = 5.505$, $p < 0.01$). Subsequent tests concerning velocity showed that the detection time for 1 deg/s was significantly longer than that for 0 deg/s and 16 deg/s (Tukey's HSD test, $p < 0.05$). As for the motion task, the main effects of color order and velocity were significant ($F(2, 10) = 5.049$, $p < 0.05$; $F(2, 10) = 23.00$, $p < 0.01$, respectively) but the other effects were not significant. Subsequent tests did not show significant differences for the color order condition, but they did show significant differences for the velocity condition. The detection time for 1 deg/s was significantly longer than that for 4 deg/s, which in turn was significantly longer than that for 16 deg/s (Tukey's HSD test, $p < 0.05$). As for the motion task, in order to examine the difference between the achromatic and chromatic conditions, the data from the conditions of red to green and green to red were pooled, and the same three-factor ANOVA was performed. The main effects of color and velocity were significant ($F(1, 5) = 4.797$, $p < 0.10$; $F(2, 10) = 28.40$, $p < 0.01$, respectively).

These results show that the change in color was detected before the change in motion when the physical changes occurred at the same time. The temporal delay to motion change was found by measuring simple reaction times. This delay is consistent with that found in previous studies of perceptual asynchrony. These results also indicate that irrelevant attributes in a task influence the detection of change. In the color task, motion velocity was an irrelevant attribute but it had a clear influence on the task. In this task, the detection time increased with the decrement of velocity, but that in the condition of 0 deg/s was exceptionally short. The former result was the same as that found by Kreegipuu, et al. (2006). They showed that motion in low velocity has an influence on the delay in response to a change in color. The result in the condition of 0 deg/s suggests that observers can respond very quickly to a change only in color without a change in motion direction. Similarly, in the motion task, the influence of velocity on the detection of change was also clearly found, but this result was the same as that of most previous studies (Hohnsbein & Mateeff, 1998; Mateeff, Dimitrov, & Hohnsbein, 1995; Mateeff & Genova, 2005; Tynan & Sekuler, 1982). On the other hand, while velocity is a relevant attribute in the motion task, color is an irrelevant attribute. As Figures 2 (b) shows, detection times for the achromatic condition were longer than those for the color condition. This suggests that a change in color plays a part to respond more quickly to a change in motion.

Although the influence of velocity was shown in both tasks of this experiment, the results of a simple detection task might not be comparable to those of previous studies of perceptual asynchrony, because perceptual asynchrony might be a phenomenon brought about by periodicity. Therefore, in Experiment 2, a test pattern with periodic changes was used. If we observe the pattern changes used in Experiment 1 repeatedly and periodically, then after the pattern disappears we should be able to predict when the attribute change will occur in the next cycle. This assumption was examined in Experiment 2.

3. Experiment 2

By using the same test patterns as those of Experiment 1, we can examine whether there is a difference between predictions of changes as a function of the observer paying attention to color or to motion. Because the test pattern has periodicity, conditions of temporal period and number of cycles were added in this experiment.

3.1. Method

3.1.1. Observers, stimuli, and apparatus

The observers, stimuli, and apparatus used in Experiment 1 were also used in this experiment. However, the color and motion direction of test patterns were reversed simultaneously within the fixed cycles.

3.1.2. Tasks and stimulus conditions

There were two tasks (color and motion), and five conditions (color order, motion order, velocity, temporal period, and number of cycles). Except for the conditions of temporal period and number of cycles, the conditions were the same as those used in Experiment 1. In the color task, there were two temporal periods (586 ms and 800 ms) and two numbers of cycles (one and three cycles). Here, one cycle means a period for stimulus presentations of red and green plaids. The two temporal periods were close in value in order to keep observers from making stereotypical responses to any stimuli in a fixed attentional set. Such responses can occur if there is only one temporal period or if there are two that are very different. There were 56 conditions in total. In the motion task, the conditions of temporal period and number of cycles were the same as in the color task, and the remaining 18 conditions were the same as those of Experiment 1, for a total of 72 conditions.

3.1.3. Procedure

The color and motion direction of the test pattern was reversed simultaneously every half-period of a cycle, for either one or three cycles. After the pattern disappeared, the observer was instructed to wait until they thought the time required for one cycle had passed and then click the mouse. In the color task, the observer was asked to ignore the change in motion direction while paying attention to the color, and click the mouse when he felt that one cycle (red to green or vice versa) of color change had passed. In the motion task, the observer was asked to ignore the change in color while paying attention to the motion direction, and click the mouse when he felt that one cycle (downward to upward or vice versa) of motion change had passed (see Figure 1 (d)). The time from the disappearance of the pattern to the mouse click was measured as the prediction time in each trial. Each observer completed 10 randomly repeated trials for each condition in each task.

3.2. Results and Discussion

The mean prediction time for each condition in each task was calculated. The mean prediction times were 715.55 ms and 763.17 ms for the color task and motion task, respectively, and the difference was 47.62 ms. Therefore, prediction times in the color task were clearly shorter than those in the motion task, indicating that the responses to changes in motion direction were slower than the responses to changes in color, irrespective of whether the patterns changed periodically. These results were the same as those of Experiment 1 and consistent with the findings of motion delay of perceptual asynchrony in previous studies. Figures 3 (a) to Figures 3 (d) show the results for the temporal periods of 586ms and 800ms for the color task and motion task, respectively. The horizontal axes in all figures indicate velocity conditions, and the vertical axes indicate the prediction times. In the motion task, the results for the chromatic and achromatic conditions are separately shown.

For the color task, an analysis of variance of five factors (color order, motion order, velocity, temporal period, and number of cycles) was performed, based on the mean prediction time for each condition in each observer. The main effects of velocity and number of cycles were

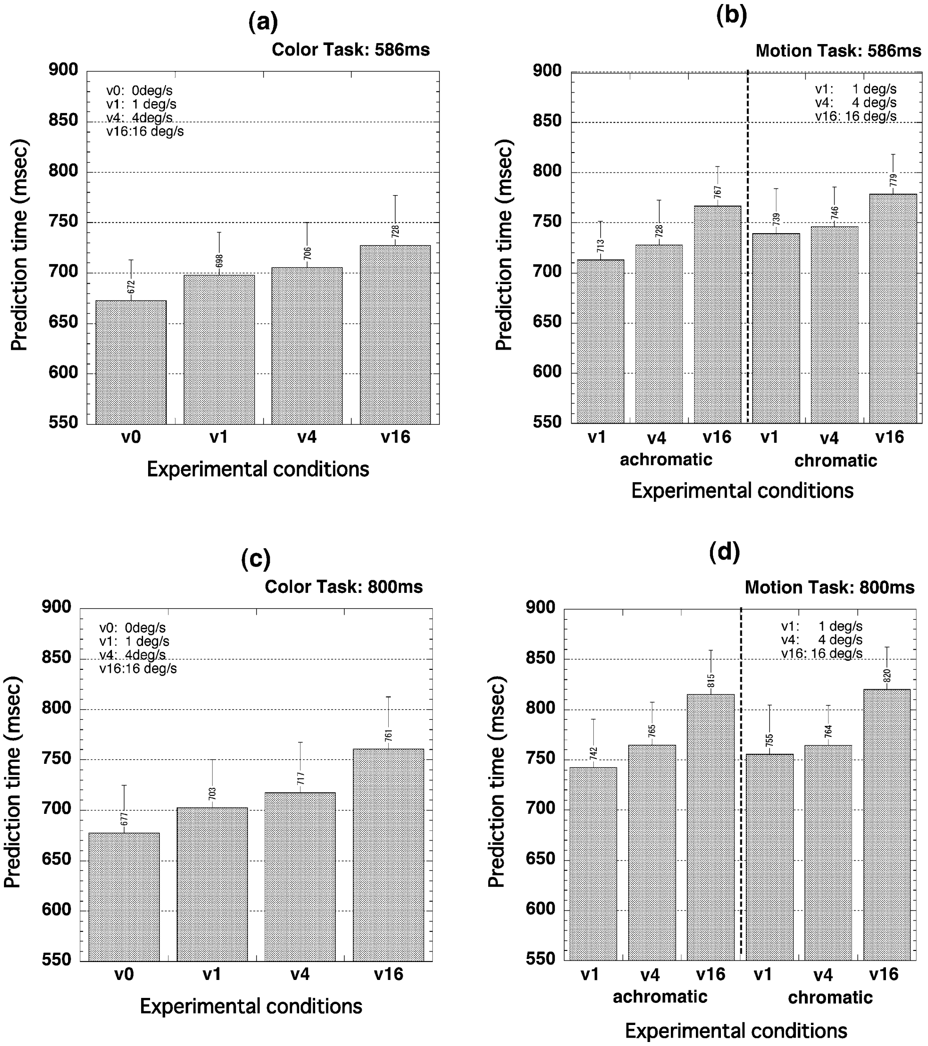

Fig. 3 Mean prediction times as a function of velocity.

(a), (b): The results for color and motion tasks under temporal period of 586ms. (c), (d): The results for color and motion tasks under temporal period of 800ms. In the motion task, the results for chromatic and achromatic conditions are shown separately. Velocity conditions: v0 (deg/s), v1 (1 deg/s), v4 (4 deg/s), and v16 (16 deg/s). Error bar indicates standard error.

significant ($F(3, 15) = 23.80$, $p < 0.01$; $F(1, 15) = 14.35$, $p < 0.05$, respectively). Subsequent tests concerning velocity showed that the differences in prediction times between any two velocity conditions, except between 1 deg/s and 4 deg/s, were significant (Tukey's HSD test, $p < 0.05$). An analysis of variance was also performed for the motion task. The main effects of velocity and number of cycles were also significant ($F(2, 8) = 13.425$, $p < 0.01$; $F(1, 4) = 10.24$, $p < 0.05$, respectively), but other effects were not significant. Subsequent tests concerning velocity showed that the prediction time for 16 deg/s was significantly longer than that for 1 deg/s and 4 deg/s (Tukey's HSD test, $p < 0.05$). As for the motion task, in order to examine the difference between the achromatic and chromatic conditions, the data in the red to green and green to red conditions were pooled, and the same ANOVA was performed. The main effects of velocity and number of cycles were significant ($F(2, 8) = 10.691$, $F(1, 4) = 12.377$, $p < 0.01$, respectively), but the effect of color was not significant.

These results show that the effect of number of cycles was significant but that of temporal period was not significant. The mean prediction times were 727 ms and 752 ms for the temporal periods of 586 ms and 800 ms, while the mean prediction times were 750 ms and 686 ms for the number of cycles (one and three), respectively. This means that the influence of the difference in the number of cycles was greater than that of the temporal period. This result is likely a result of the difference between the two temporal periods being small. In addition, the prediction time for the one cycle condition was relatively long compared with the three cycle condition. This difference may have been a result of the observers not having enough time to prepare for a response in the former condition.

In this study, however, the most important result was the influence of velocity on prediction time. As Figure 3 (a) and (c) show, the prediction time increased with the increment of velocity, including that for the condition of 0 deg/s in the color task. This influence of velocity was almost contrary to that observed in Experiment 1, indicating that motion in high velocity influences the delay in response to changes in color. Although motion velocity is an irrelevant attribute in the color task, it had a clear influence on task performance. The same influence of velocity on prediction was also observed in the motion task. As Figures 3 (b) and 3 (d) show, the prediction time increased with the increment of velocity in this task. These results were also contrary to those of Experiment 1. In this task, velocity is a relevant attribute but color is an irrelevant attribute. Although a difference between the achromatic and chromatic conditions was not significant statistically, a difference in mean prediction times between the left and right panels was clearly observed, as shown in Figures 3 (b) and 3 (d). The prediction times for the achromatic condition were shorter than those for the chromatic condition for all velocity conditions, suggesting that color has a weak but consistent influence in delaying the prediction of change in motion.

4. General Discussion

The present study showed that the response to change in motion direction is delayed compared with the response to change in color, not only in the detection task but also in the prediction task. Thus we can say that perceptual asynchrony was also confirmed in the present study. The results of our detection task in Experiment 1 were the same as those of Barbur, et al. (1998) but were different from those of Nishida and Johnston (2002). The former study showed that responses to changes in color are shorter than responses to the onset of coherent motion. The latter study showed no difference between changes in color or motion direction in an experiment of reaction times. However, there are some differences between the latter study and the present study, such as the number of subjects, their proficiency, the stimuli used, and the procedure. We do not know the exact reason for the difference in results, but we can assume that some of the abovementioned methodological differences generated the resulting differences. However, the difference between Figure 2 (a) and 2 (b) is so large that it seems quite certain that responses to changes in color were shorter than responses to changes in motion direction. This result likely supports the view that perceptual asynchrony depends on the stimulus attributes of color and motion, and that the response of the cell group engaged in color processing is quicker than that of the cell group engaged in motion processing, as Moutoussis and Zeki (1997) and Arnold and Clifford (2002) have suggested. However, there is still the possibility that the consistent delay is not based on the difference between neural responses in processing the attributes of color and motion, as Nishida and Johnston (2002) have suggested. It is not possible to draw a clear conclusion about this from the experimental results of the present study.

The experimental results also showed that other factors influenced the detection and prediction of changes: influences of color order and velocity on detection time in Experiment 1, and influences of velocity and number of cycles on prediction time in Experiment 2. Among these, the influence of velocity is particularly important because the influence of velocity on perceptual asynchrony has not been reported in previous studies (Aymoz & Viviani, 2004; Bedell et al., 2003). The results of Experiments 1 and 2, however, clearly showed the influence of velocity. The detection time in Experiment 1 decreased as velocity increased, while the prediction time in Experiment 2 increased with velocity. Since the influences of velocity in the color tasks were almost the same as those in the motion tasks in both experiments, let us consider here these influences of velocity in both tasks as a whole. The detection time results were similar to those of previous studies in which the reaction time to the onset of a moving stimulus decreased as velocity increased (Hohnsbein & Mateeff, 1998; Mateeff et al., 1995; Mateeff & Genova, 2005; Tynan & Sekuler, 1982). These results are also similar to those of studies of motion detection thresholds. It has been shown that the duration needed for motion detection decreases as velocity increases (Johnson & Leibowitz, 1976; Tayama, 2000). On the other hand, the results of velocity influences in Experiment 2 were contrary to those in Experiment 1. The prediction time of change increased with velocity in both tasks. These results are consistent with those of previous time perception studies, which have shown that perceived duration increases with velocity (Brown, 1995; Lhamon & Goldstone, 1975; Mashour, 1964; Rachlin, 1966; Tayama, 1987; Tayama et al., 1987). The prediction method used in the present study is similar to the reproduction method used in such studies of time perception. Accordingly, neither the results of Experiment 1 nor those of Experiment 2 contradicted those of previous, different studies. To better understand this apparent contradiction, let us suppose that the temporal period and the observer response to the offset of the moving stimuli in Experiment 2 were fixed. In such a case, if the response to the onset of the moving stimuli is fast, then the remaining duration will be perceived to be long.

Because if a total temporal period (t) is fixed, and if the detection time (d1) in one condition is shorter than that (d2) in another condition, which means $d1 < d2$, then we perceive the remaining duration $(t-d1)$ in the former condition as longer than that $(t-d2)$ in the latter condition. Therefore, if the response to the onset becomes faster with velocity, then the detection time will decrease with the velocity while the perceived duration will increase. The same principle might be applied to the influences of velocity on detection and prediction observed in the present study. This view is supported by the experimental results of Hohnsbein and Mateeff (1992). They showed that latencies to the offset of moving stimuli decrease with velocity in the same way as those to the onset of moving stimuli, but that the difference between latencies to the onset and offset increases with velocity.

This principle cannot be applied to perceptual asynchrony, however, because the results of asynchrony are independent of methodological differences (detection vs. prediction). This suggests that the process concerning perceptual asynchrony is different from the process concerning the influences of velocity or color on detection and prediction tasks. From all pieces of evidences, we assume that the influence of velocity and color on tasks reflects differences in the responses of a relatively peripheral neural system that depends on stimulus velocity and color, while perceptual asynchrony is different and is related to responses of a relatively higher neural system. Therefore we can not deny the possibility that there is an indirect relationship, i.e., a consistent delay in the response to the reversal of motion direction, that does not directly reflect a difference between the activities of different neural systems, as suggested by Nishida and Johnston (2002).

In this study, the influences of velocity were found not only in the motion tasks but also in the color tasks. Although velocity was an irrelevant attribute in the color task, influences of velocity were clearly observed in Experiments 1 and 2. As for the results of detection time in Experiment 1, the results were the same as those of Kreegipuu, et al. (2006), who showed that the response time to detect changes in color decreased with velocity, indicating that color coding mechanisms do not act independent of the movement parameter. The results of the present study support this view. On the other hand, the present study also showed influences of color in the motion tasks of both experiments, although the pattern color is an irrelevant attribute in motion tasks. The detection time for the achromatic condition was longer than that for the color condition, but the prediction time for the achromatic condition was the opposite, even though the latter effect was statistically not significant. Our results indicate that the motion coding mechanisms do not act independent of the color parameter and that the role of color in the detection task is different from that in the prediction task. The results also suggest that color has a facilitating influence in the detection task. We assume that the role of color is similar to that of high velocity since changes in both have the same role of strengthening the overall change. We also assume that color not only has a role in responding quickly to changes but also in lengthening the apparent temporal period, although this latter effect should be examined deeply in future studies.

The present study compared the results of the detection task with those of the prediction task. The experimental results indicated that the mechanism generating perceptual asynchrony does not have a direct relationship with the process concerning the influences of velocity and color on detection and prediction times because perceptual asynchrony was found to be independent of methodological differences, while the influences of velocity and color were dependent on methodology. Therefore, the issue of determining what process is directly related to perceptual asynchrony still remains.

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