

## Stream/bounce event perception reveals a temporal limit of motion correspondence based on surface feature over space and time

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**Abstract.** We examined how stream/bounce event perception is affected by motion correspondence based on the surface features of moving objects passing behind an occlusion. In the stream/bounce display two identical objects moving across each other in a two-dimensional display can be perceived as either streaming through or bouncing off each other at coincidence. Here, surface features such as colour (Experiments 1 and 2) or luminance (Experiment 3) were switched between the two objects at coincidence. The moment of coincidence was invisible to observers due to an occluder. Additionally, the presentation of the moving objects was manipulated in duration after the feature switch at coincidence. The results revealed that a postcoincidence duration of approximately 200 ms was required for the visual system to stabilize judgments of stream/bounce events by determining motion correspondence between the objects across the occlusion on the basis of the surface feature. The critical duration was similar across motion speeds of objects and types of surface features. Moreover, controls (Experiments 4a–4c) showed that cognitive bias based on feature (colour/luminance) congruency across the occlusion could not fully account for the effects of surface features on the stream/bounce judgments. We discuss the roles of motion correspondence, visual feature processing, and attentive tracking in the stream/bounce judgments.

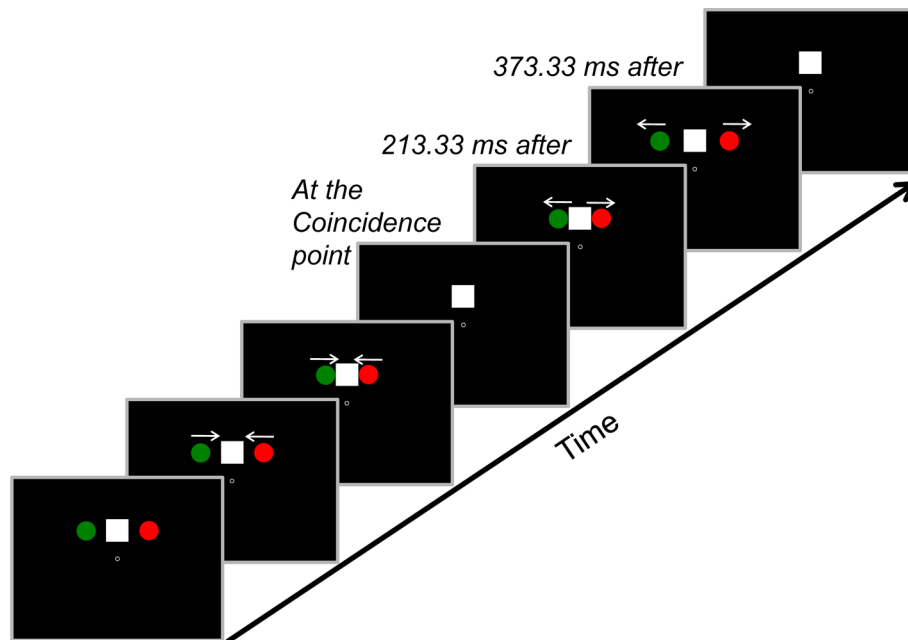
**Keywords:** motion correspondence, visual features, stream/bounce percepts

### 1 Introduction

Visual objects have unique features such as location, motion, colour, luminance, contrast, size, and shape. Because these visual features are separately processed in distinct brain areas (Livingstone and Hubel 1988), the visual system has to establish event representation by integrating the various types of visual features around us. However, it is still unclear when and how the processing for surface features such as colour and luminance affects event perception.

The way the visual system integrates visual features over space and time has been examined by employing a stream/bounce motion display. Consider two identical visual objects moving toward each other, coinciding, and then moving apart in a two-dimensional display. Observers perceive either of two motion trajectories: streaming through or bouncing off each other. Generally, in the stream/bounce display the observers predominantly perceive streaming, not bouncing (Bertenthal et al 1993; Sekuler and Sekuler 1999). However, a switch of visual features between the two objects at an occluded coincidence point can bias observers' percepts toward bouncing (Figure 1; Feldman and Tremoulet 2006). This simple demonstration suggests that the visual system solves a correspondence problem in matching the objects before coincidence with those after coincidence on the basis of the surface feature. That is, we suppose that the critical function to determine the appearance of

the stream/bounce display in the case of a feature switch is “motion correspondence based on surface feature”, in our terminology.



**Figure 1.** Examples of the stimuli used in the present study (i.e., the switch condition and 373.33 ms postcoincidence duration condition). The white arrows indicate object motion trajectories. Two objects move toward each other, enter behind from the occluder, emerge from the occluder, and continue to move until disappearing after a randomly assigned duration.

Some studies have put forward evidence that motion correspondence based on surface feature affects the judgment of motion trajectories in the stream/bounce display. Bertenthal et al (1993) reported that large differences in random-dot texture density or depth from the binocular disparity between moving objects can alter the stream/bounce event perception. Moreover, the large differences of luminance, size, and shape embedded in moving objects have been reported to influence stream/bounce event perception (Feldman and Tremoulet 2006; Sumi 1995). In particular, Feldman and Tremoulet (2006) parametrically specified the amount of feature change for moving objects, which critically modulated the appearance of the stream/bounce display. Moreover, they found that the speed of the moving objects did not affect the relationship between the amount of feature change and the stream/bounce percepts.

However, several matters remained to be clarified. Although Feldman and Tremoulet (2006) successfully demonstrated that the effect of feature change across the coincidence point was independent of the object speeds, they did not systematically control the duration or trajectory length after coincidence. Hence, it was unclear whether the critical information was the spatial or temporal extent of visual signals that was presented after coincidence. Moreover, no studies have specified the critical extent of stimuli presented after coincidence. Thus, we found that in modulating stream/bounce percepts it was also unclear to what extent spatial or temporal visual information was necessary for the visual system to determine motion correspondence between objects on the basis of the surface feature.

Consequently, we explored the temporal establishment of motion correspondence based on surface feature by assessing the establishment of stream/bounce event perception in the case of a switch of surface features. In this regard, Watanabe and Shimojo (2001) reported that the sound-induced and flash-induced bouncing percepts became saturated at the critical

duration of 150 ms to 200 ms after coincidence. To examine this matter, we introduced a colour switch (or no colour switch) to the moving objects at the occluded coincidence and varied the duration of object presentation after the coincidence (hereafter referred to as postcoincidence duration [PCD]) as did Watanabe and Shimojo (2001). The participants were asked to report whether the motion trajectories were perceived as streaming or bouncing. We hypothesized that as the PCD increased the stream/bounce judgments would become more stable, depending on motion correspondence based on surface feature. We also predicted that if the presentation duration of stimuli, rather than trajectory length, was critical after coincidence, the object speed would not influence the critical PCD to maximize the effect of an object colour switch on the stream/bounce judgments. Furthermore, it was interesting to examine whether the specific surface feature affected the critical duration.

In Experiment 1 we examined the effect of an object colour switch at coincidence on the critical PCD. In Experiment 2 we examined the effect of the object speed on the critical PCD. Then, in Experiment 3 we examined the effect of a luminance switch on the critical PCD. Finally, in Experiment 4 we ruled out the possibility that the stream/bounce judgments were exclusively governed by cognitive bias on the basis of object colour/luminance congruency across the occlusion. The results demonstrated that the critical duration was similar for a range of motion speeds and surface features. This indicates that the PCD is a crucial parameter for event perception to be influenced by the establishment of motion correspondence based on surface feature.

## 2 Experiment 1

### 2.1 Method

**2.1.1 Participants.** Five healthy adults participated in Experiment 1. Except for the author (Y.K.), all of the participants were naive to the purpose of the experiment. All participants had normal or corrected-to-normal vision.

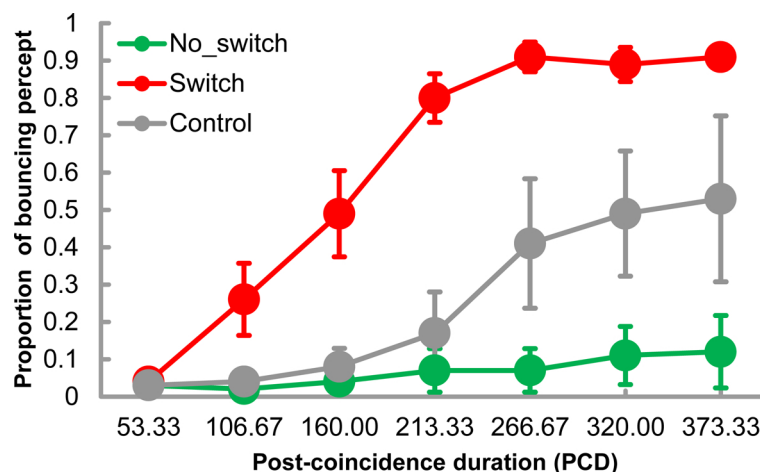
**2.1.2 Stimuli.** All stimuli were constructed using MATLAB (MathWorks Inc.) and the Cogent Graphics package (<http://www.vislab.ucl.ac.uk/cogent.php>) and were presented on a 21-inch CRT monitor (SONY GDM-F520, refresh rate 75 Hz, resolution 1024 × 768). A white fixation circle was presented at the centre of the display (96.65 cd/m<sup>2</sup>, a diameter of 0.24 deg) on a black background (0.87 cd/m<sup>2</sup>). As shown in Figure 1, the two moving objects, each with a diameter of 0.88 deg, were red and green in colour. The red and green colours were isoluminant (as measured by the flicker fusion within the Cogent Graphics package). The objects appeared separated by 2.99 deg from each other and 0.93 deg above the fixation circle. They moved horizontally toward each other at 4.00 deg/s, coincided at the midpoint, and proceeded to move away from each other. An occluder (96.65 cd/m<sup>2</sup>, 0.93 × 0.93 deg) was presented at the horizontal centre of the display but at 0.93 deg above the fixation circle, in order to prevent the participants from using the overlap cue of objects at the coincidence point in the stream/bounce event judgments. In this experiment three colour-switch conditions were applied (i.e., the no-switch condition, switch condition, and control condition). With the no-switch condition or switch condition, the coloured objects either maintained motion direction or reversed motion direction after coincidence, respectively. In the control condition the two objects were isochronous and thus shared the same colour before and after coincidence. Moreover, we manipulated the duration of object presentation after coincidence to generate seven levels (PCD: 53.33, 106.67, 160.00, 213.33, 266.67, 320.00, and 373.33 ms).

**2.1.3 Procedure.** Each participant sat approximately 80 cm away from the display and used a chin rest to stabilize the visual field. The participants were asked to judge, by pressing response keys, whether the two objects streamed through or bounced off each other. There

were three colour-switch conditions and seven PCD conditions. Each combination of conditions was repeated over 20 trials.

## 2.2 Results

Figure 2 shows the results of the experiment. A two-way repeated measures ANOVA was conducted. The main effects of both the colour switch and the PCD were significant,  $F(2, 8) = 26.82$ ,  $p < .001$ ;  $F(6, 24) = 17.32$ ,  $p < .001$ , respectively. The interaction between the colour switch and the PCD was also significant,  $F(12, 48) = 6.36$ ,  $p < .001$ . Post hoc analysis (Ryan's method) revealed that for PCD conditions of greater than 160.00 ms the proportion of bouncing percept was significantly higher with the switch condition than with the no-switch condition (all  $p < .05$ ). For PCD conditions of greater than 160.00 ms the proportion of bouncing percept was significantly higher with the switch condition than with the control condition. For PCD conditions of greater than 266.67 ms the proportion of bouncing percept with the no-switch condition was lower than with the control condition (all  $p < .05$ ). For the switch condition the proportion of bouncing percept was higher with PCD conditions of greater than 160.00 ms than with a PCD condition of 53.33 ms and was higher with PCD conditions of greater than 213.33 ms than with a PCD condition of 106.67 ms or 160.00 ms, respectively (all  $p < .05$ ). For the control condition the proportion of bouncing percept was higher with PCD conditions of greater than 266.67 ms than with a PCD condition of 53.33, 106.67, or 160.00 ms, respectively, and was higher with PCD conditions of greater than 320.00 ms than with a PCD condition of 213.33 ms (all  $p < .05$ ).



**Figure 2.** Mean proportion of bouncing percept for each condition tested in Experiment 1. The green, red, and grey circles correspond to the no-switch, switch, and control conditions, respectively. Error bars denote standard errors of mean ( $n = 5$ ).

Moreover, to characterize the temporal establishment of the bouncing percept, we fitted a logistic function to the switch condition data for each participant by using the psignifit toolbox for MATLAB (Wichmann and Hill 2001a, 2001b). The goodness of fit was evaluated on the basis of the deviance and cumulative probability estimate (criteria:  $p < .95$ ). We also calculated a “critical PCD”, which we defined as the PCD at which participants performed with a .75 proportion of bouncing percept. The critical PCD was considered as a criterion for the establishment of the bouncing percept. The estimated critical PCD averaged across the observers was 201.76 ms.

## 2.3 Discussion

We examined the critical duration that yields a stable bounce perception. The results showed that the event perception became stable with a critical PCD of 201.76 ms. That is, the results

indicated that motion correspondence between objects based on the surface feature is feasible with a critical PCD of 201.76 ms. The analysis of the proportion of bouncing percept also showed that the bounce reports were more frequent with the switch condition than with the no-switch or control conditions when the PCD was longer than 160.00 ms. These results indicated that the event perception became stable for a PCD of approximately 200 ms.

Beyond the previous finding of Feldman and Tremoulet (2006) that showed that a feature switch at coincidence strongly affects the judgment of stream/bounce events, we specified the critical PCD needed to produce stable judgments of the stream/bounce motion display through motion correspondence based on surface feature. In the present study the moment of colour switch was occluded; moreover, visual transients due to the reappearance of objects from behind the occluder were constant under all conditions. Thus, our results are not attributable to the distraction of attentive tracking at coincidence by a transient sensory signal such as a brief sound or flash (Kawabe and Miura 2006; Watanabe and Shimojo 1998, 2001). Rather, the promotion of the bouncing response with the switch condition seems to be derived from motion correspondence based on surface feature across the coincidence point.

In addition to motion correspondence based on surface feature, the integration of motion signals along a straight path might be involved in the present results. With the no-switch condition, observers rarely reported bouncing events. Previous studies have attributed this dominance of the streaming percept to motion signal integration (Bertenthal et al 1993; Kawabe and Miura 2006). It is thus possible that the dominance of the streaming percept with the no-switch condition could be attributed to motion integration along a straight path. Moreover, with the switch condition, the streaming percept was dominant with PCDs of less than 160.00 ms. The results indicate that motion integration along a straight path is more influential than motion correspondence based on surface feature until the latter is established: once the motion correspondence is established, motion integration becomes ineffective, resulting in bounce reports.

The present results also demonstrated an interesting aspect of the stream/bounce display. In this experiment we observed significant effects of the PCD with the control conditions. As the PCD became longer, the proportion of bouncing percept increased to reach the chance level. Feldman and Tremoulet (2006) have reported a similar tendency in which a small feature difference between the two objects caused a near-chance level of bounce reports. However, it is still unclear why the bouncing percepts increased only when the PCD was longer. One possible explanation is that bouncing percepts are inherently special because an object typically moves in a straight line without collision unless an obstacle exists along its motion path. The decision by the visual system may result in a bouncing percept only when the visual system successfully gathers sensory evidence (e.g., pause and disappearance) relating to a collision event within a critical duration (Goldberg and Pomerantz 1982; Sekuler and Sekuler 1999). Otherwise, the decision results in a streaming percept by default.

### 3 Experiment 2

In Experiment 2 we manipulated the object speed to determine whether the PCD or postcoincidence trajectory length were critical for the development of event perception. The speed of the objects was set twice as high as that in Experiment 1. If the PCD were critical, bouncing percepts would be established at a critical PCD similar to that in Experiment 1 (i.e., a PCD of approximately 200 ms). Conversely, if the PCD were not critical, bouncing percepts would be established at half of the critical PCD observed in Experiment 1.

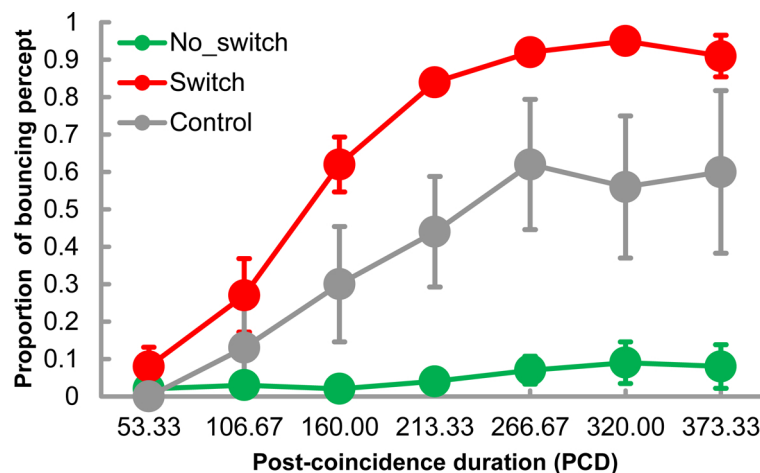
#### 3.1 Method

3.1.1 *Participants*. The 5 participants of Experiment 1 also participated in Experiment 2.

**3.1.2 Stimuli and procedure.** The stimuli were identical to those of Experiment 1, except for the following: the speed of the objects was doubled to 8.00 deg/s from the 4.00 deg/s of Experiment 1, and the objects initially appeared with a separation of 5.97 deg, so that the postcoincidence trajectory distance could not become larger than that of the pre-coincidence trajectory. The three colour-switch conditions in combination with the seven PCD conditions were applied. The procedure of Experiment 2 was identical to that of Experiment 1.

### 3.2 Results

Group mean data are shown in Figure 3. A two-way repeated measures ANOVA was conducted. The main effects of both the colour switch and the PCD were significant,  $F(2, 8) = 29.11, p < .001$ ;  $F(6, 24) = 28.35, p < .001$ , respectively. The interaction between the colour switch and the PCD was also significant,  $F(12, 48) = 6.15, p < .001$ . Post hoc analysis for the interaction effect showed that for PCD conditions of greater than 160.00 ms the proportion of bouncing percept was significantly higher with the switch condition than with the no-switch condition (all  $p < .05$ ). For PCD conditions of greater than 160.00 ms the proportion of bouncing percept with the switch condition was higher than with the control condition (all  $p < .05$ ). For PCD conditions of greater than 160.00 ms the proportion of bouncing percept was lower with the no-switch condition than with the control condition (all  $p < .05$ ). Moreover, for the switch condition the percentage of bouncing percept was higher with PCD conditions of greater than 160.00 ms than with a PCD condition of 53.33 ms or 106.67 ms, respectively, and was also higher with PCD conditions of greater than 266.67 ms than with a PCD condition of 160.00 ms (all  $p < .05$ ). For the control condition the proportion of bouncing percept was higher with PCD conditions of greater than 160.00 ms or 213.33 ms than with a PCD condition of 53.33 ms or 106.67 ms, respectively, and was higher with PCD conditions of 266.67 ms and 373.33 ms than with a PCD condition of 160.00 ms (all  $p < .05$ ).



**Figure 3.** Mean critical postcoincidence duration from curves fitted to the individual data of the switch condition for participants in each experiment. Error bars denote standard errors of mean ( $n = 5$ ).

Moreover, we fitted a logistic function to the switch condition data for each participant. We also estimated the critical PCD at 184.34 ms.

### 3.3 Discussion

Regardless of the object speed, stable judgments of the stream/bounce events were obtained for a critical duration similar to that observed in Experiment 1 (i.e., a critical PCD of approximately 200 ms). As shown in Section 4.2, no difference in critical PCD existed between Experiments 1 and 2. The analysis of the proportion of bouncing percept showed that in Experiment 2 the bounce reports were more frequent with the switch condition than with

the no-switch or control conditions when the PCD was longer than 160.00 ms. These results suggest that the critical factor in the establishment of motion correspondence based on surface feature was the PCD and not the postcoincidence trajectory length.

## 4 Experiment 3

In Experiment 3 we examined whether the critical PCD for stable stream/bounce event perception was dependent on the specific surface feature. Previous studies have shown that psychophysical impulse response (Burr and Morrone 1993) and response time (Nissen and Pokorny 1977) are slower for colour transients than for luminance transients. Given these findings, it was expected that the critical PCD would be shortened if perceptual latency differences contributed to the processing latency of motion correspondence based on surface feature. Meanwhile, it was expected that the critical PCD would be invariant if perceptual latency differences did not affect processing latency for motion correspondence based on surface feature.

### 4.1 Method

4.1.1 *Participants.* The 5 participants of Experiments 1 and 2 also participated in Experiment 3.

4.1.2 *Stimuli and procedure.* The stimuli were identical to that of Experiment 1 except for the following: a red fixation circle was presented (19.12 cd/m<sup>2</sup>) on a grey background (49.19 cd/m<sup>2</sup>); the colours of two moving objects were white (96.65 cd/m<sup>2</sup>) and black (0.87 cd/m<sup>2</sup>), respectively; and a random-dot occluder (white dots on a black background with a dot density of 50% and a luminance contrast of 98.22%) was presented. The three conditions (no-switch condition, switch condition, and control condition) in combination with seven PCDs were tested. The procedure of Experiment 3 was identical to that of Experiment 1.

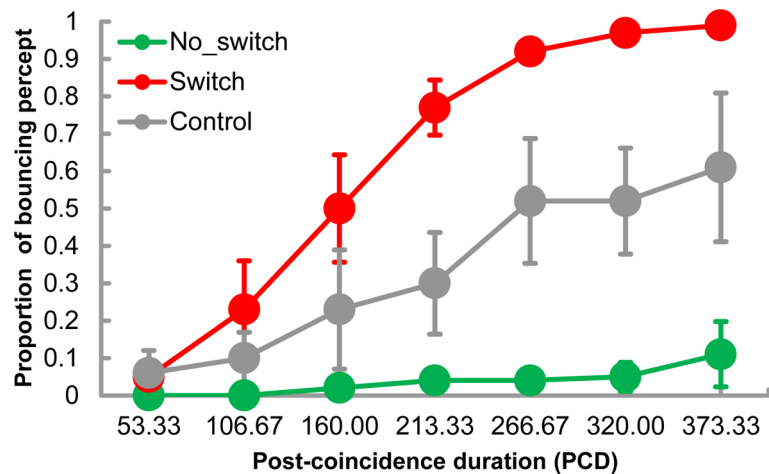
### 4.2 Results

Group mean data are shown in Figure 4. A two-way repeated measures ANOVA was conducted. The main effects of both the luminance switch and the PCD were significant,  $F(2, 8) = 30.42, p < .001$ ;  $F(6, 24) = 26.85, p < .001$ . The interaction between the luminance switch and the PCD was also significant,  $F(12, 48) = 7.14, p < .001$ . Post hoc analysis for the interaction effect showed that for PCD conditions of greater than 160.00 ms the proportion of bouncing percept was significantly higher with the switch condition than with the no-switch condition (all  $p < .05$ ). For PCD conditions of greater than 160.00 ms the proportion of bouncing percept was higher with the switch condition than with the control condition (all  $p < .05$ ). For PCD conditions of greater than 213.33 ms the proportion of bouncing percept with the no-switch condition was lower than with the control condition (all  $p < .05$ ). For the switch condition the proportion of bouncing percept was higher with PCD conditions of greater than 160.00 ms than with a PCD conditions of 53.33 ms or 106.67 ms, respectively, and was higher with PCD conditions of greater than 213.33 ms than with a PCD condition of 160.00 ms (all  $p < .05$ ). For the control condition the proportion of bouncing percept was higher with PCD conditions of greater than 266.67 ms than with a PCD condition of 53.33 ms, 106.67 ms, or 160.00 ms, respectively (all  $p < .05$ ).

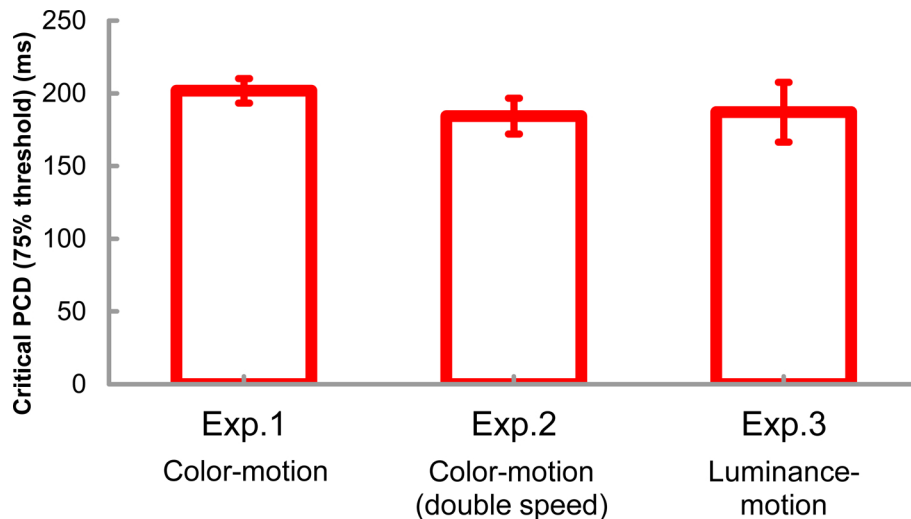
Moreover, we fitted a logistic function to the switch condition data for each participant. We also estimated the critical PCD at 187.10 ms (Figure 5). As proved by a one-way ANOVA for the critical PCDs with the experiments as a factor, the main effect of the experiments was not significant ( $F_{2, 8} = 0.346, p = .72$ ).

### 4.3 Discussion

The results of Experiment 3 showed that the critical duration for the establishment of bouncing percept with the luminance switch was as much as that with the colour switch:



**Figure 4.** Mean proportion of bouncing percept for each condition tested in Experiment 2. The green, red, and grey circles correspond to the no-switch, switch, and control conditions, respectively. Error bars denote standard errors of mean ( $n = 5$ ).



**Figure 5.** Mean proportion of bouncing percept for each condition tested in Experiment 3. The green, red, and grey circles correspond to the no-switch, switch, and control conditions, respectively. Error bars denote standard errors of mean ( $n = 5$ ).

that is, a PCD of approximately 200 ms. The analysis of the proportion of bouncing percept also showed that the temporal patterns of the data were similar in Experiments 1 and 3. These results indicate that differences in processing latency do not affect processing speed for motion correspondence based on surface feature. In other words, the temporal pattern is feature invariant for motion correspondence based on surface feature.

## 5 Experiments 4a–4c

In Experiment 4 we examined whether participants in previous experiments had inferred and judged the stream/bounce events solely on the basis of object colour/luminance congruency across the occlusion. If stream/bounce judgments were determined only by the cumulative evidence of feature congruency over time, the temporal pattern of a same/different judgment of object feature across the occlusion would depend on the PCD as the stream/bounce judgments did.



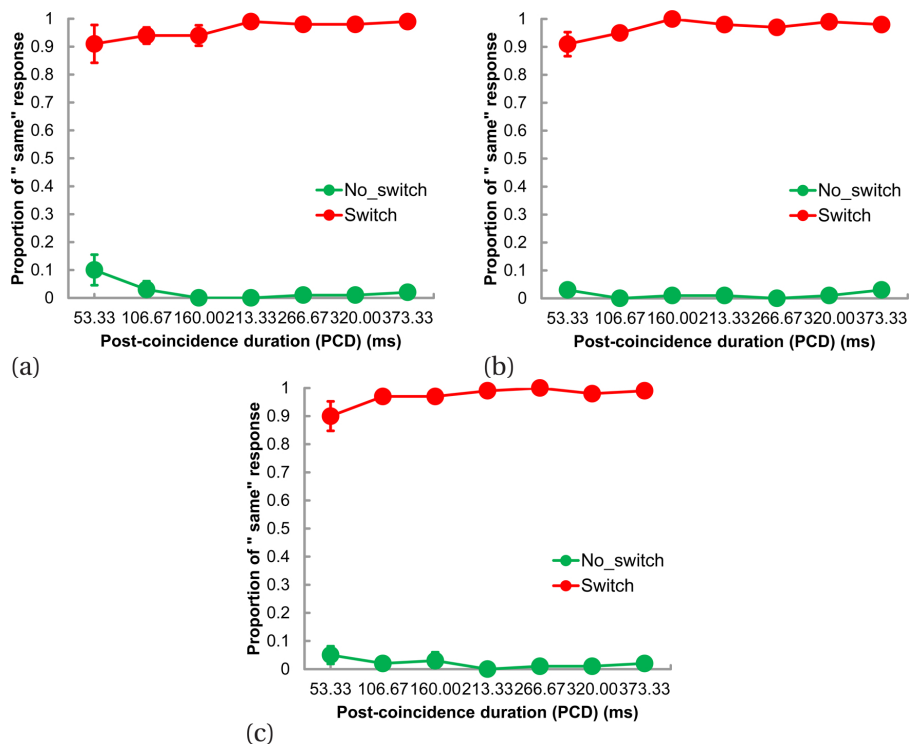
## 5.1 Method

5.1.1 *Participants.* The 5 participants of the previous three experiments, including one of the authors, also participated in Experiments 4a, 4b, and 4c.

5.1.2 *Stimuli and procedure.* The stimuli of Experiments 4a, 4b, and 4c corresponded to those of Experiments 1, 2 (double-speed version of Experiment 1), and 3 (luminance version of Experiment 1), respectively, except for the following: there were two conditions (the no-switch condition and switch condition) for colour (in Experiments 4a and 4b) and luminance (in Experiment 4c). In this experiment the participants were asked to judge, by pressing response keys, whether the colour/luminance of the objects at the left/right sides was the same or different before and after the occlusion.

## 5.2 Results

Group mean data for each experiment are shown in Figure 6. A two-way repeated measures ANOVA was conducted for each experiment. The main effect of the feature switch was not significant in Experiment 4a,  $F(1, 4) = 1925.44$ ,  $p < .001$ ; Experiment 4b,  $F(1, 4) = 13360.03$ ,  $p < .001$ ; or Experiment 4c,  $F(1, 4) = 1784.93$ ,  $p < .001$ . The main effect of the PCD was not significant in Experiment 4a,  $F(6, 24) = 0.41$ ,  $p = .86$ ; Experiment 4b,  $F(6, 24) = 1.20$ ,  $p = .34$ ; or Experiment 4c,  $F(6, 24) = 1.03$ ,  $p = .43$ . The interaction between the feature switch and the PCD was not significant in Experiment 4a,  $F(6, 24) = 2.32$ ,  $p = .07$ ; Experiment 4b,  $F(6, 24) = 2.48$ ,  $p = .05$ ; or Experiment 4c,  $F(6, 24) = 2.07$ ,  $p = .09$ .



**Figure 6.** Mean proportion of the “same” response for each condition tested in (a) Experiment 4a, (b) Experiment 4b, and (c) Experiment 4c. The green and red circles correspond to the no-switch and switch conditions, respectively. Error bars denote standard errors of mean ( $n = 5$ ).

## 5.3 Discussion

The results of Experiment 4 indicated that the judgment of feature congruency has no clear dependency on the PCD. This insignificant PCD dependence observed in Experiment 4 revealed a fairly different pattern from that of the stream/bounce judgments in the previous

experiments. These findings suggest that the stream/bounce judgments cannot simply be attributed to the judgments of the spatial feature congruency.

Moreover, the results of Experiment 4 suggest that the reason for the predominant streaming percept under relatively shorter PCD conditions (less than 160.00 ms) is not that participants failed to perceive a colour/luminance switch between the two objects in motion. With the shorter PCDs in combination with the feature switch, observers tend to perceive the streaming event regardless of the distinct identities of the objects. On the basis of informal reports by observers, Bertenthal et al (1993) addressed the fact that the visual system could accommodate the discrepancy between the perceived directions and distinct identities of the objects. In other words, motion integration along the trajectories was sufficiently compelling to contradict feature congruency. As mentioned in the discussion of Experiment 1, we conclude that motion integration along a straight path is more influential than motion correspondence based on surface feature, especially for the shorter PCDs.

## 6 General discussion

In the present study we examined when motion correspondence based on surface feature was established by examining the critical PCD for stable stream/bounce percepts. Consistent with the results of a previous study (Feldman and Tremoulet 2006), in all experiments the switch of the surface feature across the coincidence strongly modulated the stream/bounce event perception. Moreover, the present study newly demonstrated that the stable stream/bounce percepts required a critical PCD of approximately 200 ms, regardless of the object speed and the type of surface feature. We therefore suggest that the duration of stimulus presentation after coincidence is a critical parameter for motion correspondence based on surface feature to affect the stream/bounce event perception.

With the results of Experiment 4 we confirmed that the results of Experiments 1 to 3 were not simply attributable to a cognitive bias related to the stream/bounce event inference based on object colour/luminance congruency in space (e.g., Watanabe and Shimojo 2001). The results of Experiment 4 showed that the judgments of the spatial congruency for colour/luminance did not clearly depend on the PCDs. Thus, the judgment of the spatial feature congruency probably is grounded on the different mechanism from the judgment of the streaming/bouncing motion trajectory in the presence of surface feature change of moving objects. On the basis of these results and discussions, we propose that the temporal establishment of motion correspondence based on surface feature is a necessary condition for feature switch to affect the stream/bounce event perception.

Moreover, we suggest that the findings of the present study may be irrelevant to colour/luminance detection in a dynamic display. The previous studies reported that the detection threshold for colour change (Monnier and Shevell 2004) and the response latency to colour/luminance change (Kreegipuu et al 2006) both decreased as motion speed increased. Kreegipuu et al suggested that colour change detection was promoted because a greater number of colour coding units can be activated along the motion trajectory with an increased object speed. By contrast, our results demonstrated that the critical PCD was independent of the object speeds. Moreover, the results of Experiment 3 showed that the latency difference between detections of luminance and colour did not change the critical PCD. These results indicate that a detection mechanism of the type reported by Kreegipuu et al (2006) does not participate in determining the processing speed of motion correspondence based on surface feature to affect stream/bounce event perception.

Here we discuss the relationship between motion correspondence based on surface feature and attentive tracking in the stream/bounce motion display. First, the critical PCD obtained in this study (i.e., approximately 200 ms) is similar to the temporal limit of attentive

tracking reported in previous studies using apparent motion stimuli without interstimulus interval (160 ms: Benjamins et al 2007; 200 ms: Holowitz et al 2004). Watanabe and Shimojo (2001) also mentioned the potential involvement of attentive tracking in stream/bounce percepts. In particular, they suggested that in relation to a stream/bounce decision, extraction of motion direction might occur at the level of attentive tracking. In our stimuli the motion reversal was characterized by the colour/luminance switch. Hence, it is possible that attentive tracking is responsible for motion correspondence based on surface feature. Furthermore, another line of research on multiple-object tracking has shown that a colour change in a moving object is detected only when sufficient attentional resources are deployed to a transient signal of colour change (Baharami 2003). Taken together, the critical PCD in the present results is perhaps a reflection of the temporal limits of attentive tracking in the determination of motion correspondence based on surface feature. Future studies will better define the role of attentive tracking in motion correspondence based on surface feature and thus in stream/bounce percepts.

Finally, we consider the similarity between the temporal limit in the present study and that of colour-motion binding in a previous study (Arnold 2005; for a review see Holcombe 2009). Arnold (2005, Experiment 3) reported an upper limit of 2–3 Hz for correct pairing of colour and motion, using a sinusoidal grating that oscillated between different pairs of colours (red/green) and motion directions (leftward/rightward). This limit expresses 165–250 ms in terms of duration of half-cycle stimuli. The temporal limit of colour–motion binding is akin to the critical PCD that caused the dominance of bounce reports in the present study. However, because the previous study on colour–motion binding used periodically oscillating stimuli, unlike the present study, it would be premature to assert that colour–motion binding contributes to the effects of colour switch on stream/bounce judgments. Further investigation of the temporal limit using aperiodic colour–motion stimuli will provide meaningful insights into momentary feature binding in the ever-changing environment.

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