

## The effect of perceptual learning on the sensitivity and stability of double fusion in Panum' s limiting case

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### Abstract

Panum' s limiting case is a typical phenomenon of monocular occlusion in binocular vision. It occurs naturally when one object is occluded by another object for one eye, but in the other eye the two objects are located in different directions. Only recently has it been found that in addition to horizontal disparity, the vertical disparity gradient and cue conflict are two important determinants for double fusion. Therefore, the current study aims to determine the relationship between the two determinants and perceptual learning in Panum' s limiting case. Twenty-six observers were trained for five days. Meanwhile, the RTs and duration of double fusion was measured when the participants viewed several versions of Panum' s configuration. In these stimuli, vertical disparity gradient was varied from 0.1 to 0.6 and cue conflict was manipulated from low to high. The results revealed that for each level of these factors, the RTs of double fusion decreased and the duration of double fusion increased with each training session. Moreover, there were significant differences among different levels of vertical disparity gradient and cue conflict. Lastly, there was also a significant interaction effect between the two determinants in Panum' s limiting case. These results suggest that there is perceptual learning for each level of the two determinants in monocular occlusion and these factors jointly affect the sensitivity and stability of double fusion.

### Full Text

#### Preamble

The Effect of Perceptual Learning on the Sensitivity and Stability of Double Fusion in Panum' s Limiting Case

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**Author Contributions:** All authors contributed to the design of the study and preparation of the manuscript. Yuyu Shi proposed the experimental design. Yanyan Gao and Jing Ren acquired and analyzed the data. Ashley Chung-Fat-Yim, Huayun Li, and Xize Jia contributed to manuscript revisions.

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## Abstract

Panum's limiting case represents a classic phenomenon of monocular occlusion in binocular vision, occurring naturally when one object occludes another for one eye while both objects appear in different directions to the other eye. Only recently have researchers discovered that beyond horizontal disparity, the vertical disparity gradient and cue conflict serve as two important determinants for double fusion. The current study therefore aimed to investigate the relationship between these two determinants and perceptual learning in Panum's limiting case. Twenty-six observers underwent five days of training while we measured their reaction times (RTs) and duration of double fusion across various Panum configurations. In these stimuli, the vertical disparity gradient varied from 0.1 to 0.6, and cue conflict was manipulated from low to high. The results revealed that for each level of these factors, RTs for double fusion decreased while duration increased with each training session. Moreover, significant differences emerged among different levels of vertical disparity gradient and cue conflict. Critically, a significant interaction effect between the two determinants was observed in Panum's limiting case. These findings suggest that perceptual learning occurs for each level of the two determinants in monocular occlusion and that these factors jointly influence the sensitivity and stability of double fusion.

**Keywords:** monocular occlusions, Panum's limiting case, vertical disparity gradient, cue conflict, double fusion, training

## 1. Introduction

When viewing the world binocularly, the visual system receives two slightly different images of the same scene projected to each eye. Stereopsis is the process responsible for reconstructing three-dimensional (3D) depth perception from these two distinct two-dimensional (2D) images (Wheatstone, 1838). In natural scenes, one object may occlude another in one eye, resulting in perception of only one object in that eye, while both objects remain visible at different distances in the other eye. This condition creates monocular areas in the two eyes, a

phenomenon referred to as “monocular occlusion” (Kaye, 1978; Tsirlin et al., 2014). Since Wheatstone’s invention of the stereoscope in 1838, the majority of stereoscopic research has focused on understanding how binocular disparity contributes to depth perception (Harris & Wilcox, 2009; Howard & Rogers, 2012), with little attention paid to the role of occluded regions, which were typically treated as noise during 3D image reconstruction. Only in the past two decades has interest grown in demonstrating that the visual system can estimate depth in occluded regions (Anderson & Julesz, 1995; Gillam & Borsting, 1988; Nakayama & Shimojo, 1990).

One of the simplest phenomena involving monocular occlusion in binocular depth perception is Panum’s limiting case (Gillam et al., 1995; Panum, 1858). This occurs when one eye is presented with a single feature while the other eye receives two horizontally offset features. Such a configuration is consistent with a pair of real objects located at different distances (see Fig. 1 [Figure 1: see original paper]): the closer object occludes the more distant one for the left eye but not for the right eye. Although the depth mechanism of Panum’s limiting case is important for establishing theories of stereopsis, it has long been a subject of controversy in binocular vision research (Ono et al., 1992).

The debate surrounding Panum’s limiting case centers on whether perceived depth derives from double fusion or single fusion. On one hand, evidence supporting double fusion demonstrates that when disparity is small, depth perception occurs through matching the single feature presented to one eye with the two features presented to the other eye (Gillam et al., 1995; Gillam et al., 2003; Kumar, 1996). On the other hand, advocates of single fusion propose that only one feature results from binocular matching while the other originates from alternative cues (Frisby, 2001; Ono et al., 1992; Shimono et al., 1999; Wang et al., 2001). Only recently has research revealed that beyond disparity, the vertical disparity gradient and cue conflict constitute two important factors influencing final depth perception in Panum’s configuration (Li et al., 2012). The vertical disparity gradient refers to the ratio of the difference between minimum and maximum disparity point pairs in the configuration to the binocular separation (Bülthoff et al., 1991; Burt & Julesz, 1980). Cue conflict (see Figure 2 [Figure 2: see original paper]) refers to the conflict between various cues that provide information for depth perception; in this study, it specifically denotes the inconsistency between the two-dimensional shape provided by monocular cues and the three-dimensional shape provided by binocular parallax (Allison & Howard, 2000). Moreover, recent evidence from Li and colleagues has shown that double fusion consistently occurs during the stereopsis process (H. Li et al., 2011). Consequently, this study examined the effects of vertical disparity gradient and cue conflict on double fusion.

Perceptual learning is well known to generate performance improvements through repeated exposure and practice on sensory tasks, with training-induced plasticity established across various visual tasks ranging from simple attribute discrimination to more complex sensory judgments (Hussain et al., 2009;

Tsodyks & Gilbert, 2004). Simple tasks include orientation identification, direction discrimination, or motion detection (Ball & Sekuler, 1987; Huang et al., 2007; J. et al., 2015; Shiu & Pashler, 1992), while complex tasks involve face identification, video game playing, or contour judgment (Gold et al., 1999; R. W. Li et al., 2011; Mckendrick & Battista, 2013). Many studies have demonstrated both rapid and slow learning stages in the time course of perceptual learning, though the time course in Panum's limiting case remains uncertain, as does the relationship between perceptual learning and the determinants of stereopsis in this context.

Previous studies on Panum's limiting case have primarily focused on stimulus types or forms while neglecting several important aspects and lacking further research on perceptual learning in stereoscopic vision. First, prior research rarely considered the effect of stereoscopic experience on depth perception outcomes. Some studies used both experienced and inexperienced subjects without distinguishing between their results (Bingushi & Yukumatsu, 2010; Wang et al., 2001). However, experienced subjects were more likely to perceive double fusion while inexperienced subjects tended toward single fusion, potentially confounding true double fusion results. Second, when stimuli were presented briefly, subjects' perceptual results remained unstable; even with identical stimuli, subjects might perceive different results at different times. Moreover, the perceptual result of double fusion requires time to develop (Spang et al., 2012). Therefore, short presentation times may bias subjects toward perceiving single fusion. Third, in previous studies examining factors affecting perceptual outcomes, subjects reported whether they perceived double fusion, with the number of double fusions across all subjects serving as the dependent variable (Wang et al., 2001). However, since frequency represents discrete, non-normally distributed data, parametric testing cannot be conducted, preventing analysis of interactions among influencing factors.

This study investigates the relationship between the two determinants (vertical disparity gradient, cue conflict) and perceptual learning in monocular occlusion. Compared to previous research with similar themes, the current study offers several methodological strengths. We selected only inexperienced subjects and set the stimulus response time to 10 seconds to provide adequate time for perceptual responses. Subjects could press buttons multiple times to report their perceptual results at any point during this period. Additionally, we used reaction time and duration as dependent variables to examine whether a rapid learning stage exists in Panum's limiting case. We measured RTs and duration of double fusion while training observers for five days, with vertical disparity gradient varying between 0.1, 0.3, and 0.6, and cue conflict manipulated from low to medium to high. Based on existing literature, we hypothesized performance improvements for each level of the two determinants after training, with both determinants affecting the sensitivity and stability of double fusion. Additionally, we hypothesized significant differences among different levels of these factors.

## 2.1 Observers

A total of 26 undergraduate and graduate students aged 22 to 29 years were recruited through open advertisement, including 14 males and 12 females. None had prior stereopsis experience. All observers provided written informed consent, had normal or corrected-to-normal visual acuity, and demonstrated good stereoscopic acuity as measured by the Randot™ stereoacuity test (at least 20 seconds of arc). The study was approved by the research ethics board at Southeast University and followed the tenets of the Declaration of Helsinki.

## 2.2 Apparatus

Stimulus presentation scripts were executed on a G5 Macintosh computer using Matlab version 2.54 of the Psychtoolbox extensions (Brainard, 1997; Pelli, 1997). Stimuli were presented on a pair of CRT monitors (ViewSonic G225f) arranged in a mirror stereoscope at a viewing distance of 60 cm. Monitor resolution was 1280×960 pixels with a refresh rate of 75 Hz. Participants were seated in a dark room with their heads stabilized by a chin rest to minimize head movement.

## 2.3 Stimuli

All stimuli included a single feature presented to one eye and two features presented to the other eye. Vertical disparity gradient varied between 0.1, 0.3, and 0.6, while cue conflict was manipulated from low to medium to high (see Fig. 3 [Figure 3: see original paper]). Each experimental condition included three types of stereoscopic stimuli depicting Panum’s limiting case (i.e., Gillam, Frisby, and Wang series), resulting in a total of 54 stimulus types.

## 2.4 Design and Procedure

The study consisted of six sessions: one preliminary session and five training sessions, with identical instructions across all sessions. Participants were instructed to distinguish between “single” or “double” fusion for each stimulus and told there were no correct answers—they simply needed to press a button to report whether they perceived “single” or “double” fusion. Double fusion was defined as both features having 3D depth after fusion, while single fusion referred to only one of the two features having 3D depth after fusion. After understanding these criteria, participants completed nine practice trials in the preliminary session, followed by five training sessions (day 1, day 2, day 3, day 4, and day 5) scheduled consecutively for approximately twenty minutes each day. Each training session presented all 54 stimulus types.

On each trial (see Fig 4 [Figure 4: see original paper]), two rectangles appeared for an unlimited duration. Once participants fused these rectangles, they pressed the ‘Space’ key to begin the trial. The stimulus (target features inside the rectangle) then appeared on screen for 10 seconds. When participants perceived double fusion, they pressed ‘S’ as quickly and accurately as possible. If their

perception changed to single fusion, they pressed 'F'. During the 10-second period, they could press either key as many times as needed if their perception changed. If they did not perceive double fusion after stimulus onset, they were instructed not to press any key until the 10 seconds elapsed. Regardless of how many times observers pressed keys, the stimulus remained on screen for the full 10 seconds. After the stimulus disappeared, the two rectangles reappeared and participants began a new trial.

## 2.5 Data Analysis

Double fusion data were calculated separately for all observers. If a participant pressed no key, RT was recorded as 10 seconds and duration as 0 seconds for analysis. If perception changed during the 10-second period, the program recorded the first time double fusion was perceived as RT and calculated the total time double fusion was perceived as duration.

Statistical analyses were conducted using Statistica 7.0 (StatSoft Inc). Two separate three-way ( $3 \times 3 \times 5$ ) repeated-measures ANOVAs were performed for mean RTs and duration of double fusion. The three factors were vertical disparity gradient (0.1, 0.3, and 0.6), cue conflict (low, medium, and high), and training session (day 1, day 2, day 3, day 4, and day 5). A Greenhouse-Geisser correction was applied when sphericity was violated, and post-hoc t-tests (Bonferroni corrected for multiple comparisons) were performed when necessary.

### 3.1 The Results of RTs for Double Fusion

There was a main effect of vertical disparity gradient,  $F(2, 50) = 46.85, p < .001, p^2 = .63$ . Post-hoc paired t-tests revealed that RT for the disparity gradient of 0.1 ( $M = 3.24, SE = .31$ ) was significantly shorter than for 0.3 ( $M = 4.12, SE = .35$ ) and 0.6 ( $M = 5.31, SE = .42$ ), both  $ps < .001$ . RT for disparity gradient 0.3 was significantly shorter than for 0.6,  $p < .001$ . There was also a main effect of cue conflict,  $F(2, 50) = 41.62, p < .001, p^2 = .31$ . Post-hoc paired t-tests revealed that RT for high cue conflict ( $M = 6.12, SE = .45$ ) was significantly longer than for medium ( $M = 3.35, SE = .37$ ) and low ( $M = 3.21, SE = .38$ ),  $ps < .001$ . Moreover, the main effect of training was significant,  $F(4, 100) = 11.45, p < .001, p^2 = .29$ . Post-hoc paired t-tests revealed that RT for day 1 ( $M = 4.92, SE = .32$ ) was significantly longer than for day 3 ( $M = 4.07, SE = .41$ ), day 4 ( $M = 3.87, SE = .38$ ), and day 5 ( $M = 3.64, SE = .38$ ), all  $ps < .004$ . RT for day 2 ( $M = 4.63, SE = .35$ ) was significantly longer than for day 3, day 4, and day 5,  $ps < .01$ .

For the interaction effect, results revealed a significant interaction between vertical disparity gradient and cue conflict,  $F(4, 100) = 12.88, p < .001, p^2 = .34$  (see Fig 5 [Figure 5: see original paper]). For all three levels of vertical disparity gradient, RTs for high cue conflict were significantly longer than for medium and low cue conflict, all  $ps < .001$ . Notably, the 0.1 and 0.3 vertical disparity gradient conditions showed marginal differences between low and

medium cue conflict,  $ps < .05$ , with RTs for medium conflict longer than for low conflict. However, for the 0.6 vertical disparity gradient condition, RTs for medium conflict were significantly shorter than for low conflict,  $ps < .02$ .

The RT results for the two factors (vertical disparity gradient and cue conflict) by training session are presented in Figures 6 and 7, respectively. Although interaction effects between these factors and training session were not significant, RTs for all successive levels decreased from day 1 to day 5, with RTs for double fusion decreasing with each training session. Paired sample t-tests confirmed that RTs for every level of both factors were significantly different between day 1 and day 5, all  $ps < .001$ .

### 3.2 The Results of Duration for Double Fusion

A three-way ANOVA on duration of double fusion revealed a main effect of vertical disparity gradient,  $F(2, 50) = 49.52$ ,  $p < .001$ ,  $p^2 = .67$ . Post-hoc paired t-tests revealed significant differences between each level of disparity gradient,  $ps < .001$ . Specifically, duration for 0.1 disparity gradient ( $M = 6.69$ ,  $SE = .31$ ) was significantly longer than for 0.3 ( $M = 5.78$ ,  $SE = .35$ ) and 0.6 ( $M = 4.53$ ,  $SE = .42$ ), and duration for 0.3 disparity gradient was significantly longer than for 0.6,  $p < .001$ . There was also a significant main effect of cue conflict,  $F(2, 50) = 45.01$ ,  $p < .001$ ,  $p^2 = .64$ . Post-hoc paired t-tests revealed that duration for high cue conflict ( $M = 3.72$ ,  $SE = .44$ ) was significantly shorter than for medium ( $M = 6.56$ ,  $SE = .36$ ) and low ( $M = 6.73$ ,  $SE = .38$ ),  $ps < .001$ . Moreover, the main effect of training was significant,  $F(4, 100) = 10.43$ ,  $p < .001$ ,  $p^2 = .29$ . Post-hoc paired t-tests revealed that duration for day 1 ( $M = 4.98$ ,  $SE = .31$ ) was significantly shorter than for day 3 ( $M = 5.84$ ,  $SE = .40$ ), day 4 ( $M = 6.03$ ,  $SE = .38$ ), and day 5 ( $M = 6.22$ ,  $SE = .38$ ), all  $ps < .01$ . Duration for day 2 ( $M = 5.28$ ,  $SE = .35$ ) was significantly shorter than for day 3, day 4, and day 5,  $ps < .05$ .

For the interaction effect, results revealed a significant interaction between vertical gradient and cue conflict,  $F(4, 100) = 12.58$ ,  $p < .001$ ,  $p^2 = .34$ . No other interaction effects were significant,  $ps > .05$ .

The duration results for the relationship between the two factors (vertical disparity gradient and cue conflict) and training session are shown in Figures 8 and 9, respectively. Although interaction effects between these factors and training session were not significant, duration for successive levels increased from day 1 to day 5, with duration of double fusion increasing as training sessions progressed. Paired t-tests confirmed significant differences between day 1 and day 5 for duration at every level of both factors, all  $ps < .001$ , with day 1 duration significantly shorter than day 5 at every level.

## 4 Discussion

This study examined the relationship between two determinants of stereopsis (vertical disparity gradient and cue conflict) and perceptual learning. Results showed that for each level of both factors, RTs and duration of double fusion on day 1 differed significantly from day 5, providing evidence that perceptual learning occurred across both determinants. Furthermore, main effects of vertical gradient and cue conflict were significant for both RTs and duration of double fusion. Additionally, the interaction effect between vertical gradient and cue conflict on double fusion reached significance. These findings suggest that vertical disparity gradient and cue conflict are crucial factors for depth perception in Panum's limiting case, and that these determinants jointly affect the sensitivity and stability of double fusion in stereopsis.

### 4.1 The Relationship Between Vertical Disparity Gradient and Perceptual Learning

Consistent with previous studies demonstrating the role of vertical disparity gradient in stereoscopic fusion (Bülthoff et al., 1991; Burt & Julesz, 1980; Mckee & Vergheze, 2002; Yu et al., 2017), the present study corroborated and extended prior findings by showing that smaller vertical disparity gradients produced shorter RTs for double fusion but longer durations. Additionally, compared to Li et al. (2012), which used frequency of reported double fusion to investigate this determinant, this study developed a more innovative measure to examine vertical gradient effects on depth perception. Specifically, by using three-way repeated-measures ANOVAs on RTs and duration of double fusion, we could evaluate interaction effects among factors—something difficult to achieve with frequency data, which require non-parametric tests (e.g., Cochran's Q test and McNemar's test) that cannot easily assess interactions among more than two factors (Nelder, 1965; Somes & Bhapkar, 1977).

It is widely accepted that perceptual learning generates visual performance improvements across various tasks (Ball & Sekuler, 1987; Huang et al., 2007; O'Toole & Kersten, 1992; Zhou et al., 2006). Our study examined perceptual learning for the sensitivity and stability of double fusion using Panum's limiting case stimuli. Results revealed that for all vertical gradient levels, RTs for double fusion on day 1 were significantly longer than on day 5, while duration showed the opposite pattern. As training progressed from day 1 to day 5, RTs for double fusion decreased gradually while duration increased gradually, suggesting that perceptual learning occurred for each level of vertical gradient.

### 4.2 The Relationship Between Cue Conflict and Perceptual Learning

Consistent with our hypothesis for cue conflict, a significant main effect emerged among the three levels. Further analyses revealed that high conflict differed significantly from medium and low conflict for both RTs and duration of double fusion, confirming effective manipulation of cue conflict. Previous research

demonstrated that cue conflict affects depth perception (Pizlo et al., 2005), and our results additionally showed that for each cue conflict level, RTs for double fusion gradually decreased while duration gradually increased as training progressed from day 1 to day 5, indicating that perceptual learning occurred at each level of cue conflict.

Based on these results, it is worth noting that while high conflict differed significantly from medium and low conflict, medium and low cue conflict were quite similar. Although further analyses revealed differences between medium and low cue conflict in the two-way interaction, the main effect between medium and low conflict was not significant. These interesting findings deserve further examination. In fact, Li and colleagues (2012) noted that the conflict degree for medium was only slightly higher than for low. Our results align with this previous work, jointly illustrating that the three-level manipulation of cue conflict is not equidistant: the degree of low conflict differs substantially from medium and high conflict, while medium and low conflict are quite similar.

### **4.3 The Effects and Time Course of Perceptual Learning in Panum's Limiting Case**

Across all levels of vertical disparity gradient and cue conflict, perceived responses to double fusion decreased gradually with increased training days while duration increased gradually, indicating significant perceptual learning effects for both factors. In Panum's limiting case, perceptual learning primarily involves learning about these factors. Learning specific to the vertical disparity gradient and cue conflict in the stimulus configuration reflects the specificity of perceptual learning—that is, when stimulus orientation or position changes, the training effect must be relearned to achieve previous performance levels (Poggio et al., 1992). However, transfer was observed across different levels of vertical disparity gradient and cue conflict, as well as across later training days, where previous training effects were retained or learning accelerated when approaching subsequent tasks (Ahissar & Hochstein, 1997; Liu & Weinshall, 2000).

Previous studies have suggested that perceptual learning involves both fast and slow learning stages, though no obvious fast learning stage emerged in this study. Two possible explanations exist. First, the task difficulty in this study may have been too high for a significant rapid learning stage to appear (Avi et al., 1997). Second, research on minimum training amounts in perceptual learning has proposed the concept of a critical amount, suggesting that learning effects only emerge when this critical amount is satisfied (Wright & Sabin, 2007). However, the critical amount differs across tasks and stimuli, and the small training amount in this study may have prevented a significant rapid learning stage from manifesting.

#### 4.4 The Effects of Vertical Disparity Gradient and Cue Conflict on Stereopsis

Results showed significant main effects for both vertical disparity gradient and cue conflict, indicating that these two factors crucially influence double fusion, consistent with previous research. Unlike prior studies, we used response time and duration as dependent variables, and further analysis revealed a significant interaction between vertical disparity gradient and cue conflict. Specifically, when vertical disparity gradient was 0.1 and 0.3, higher cue conflict degrees produced shorter average RTs for double fusion and shorter durations. However, when vertical disparity gradient was 0.6, no consistent pattern emerged for cue conflict effects on average RT and duration. This may reflect that under 0.6 vertical disparity gradient conditions, subjects could barely perceive double fusion, preventing accurate measurement of cue conflict's impact on double fusion.

#### 4.5 Limitations and Future Directions

Although our study yielded interesting conclusions, one limitation involves response coding. As noted, if participants failed to perceive double fusion during stimulus presentation, RTs were recorded as 10 seconds and duration as 0 seconds. While this does not affect overall trends for each factor, it may underestimate differences among mean values across experimental conditions. For example, if results for just a few observers differ substantially from the majority, mean RTs and durations across all observers may deviate from the majority pattern, potentially making mean RTs longer or mean duration shorter. Future studies should consider using presentation durations longer than 10 seconds.

The frequency data recorded over 10 seconds can be found in the Supplementary Materials.

Future research should examine the neural correlates of these two determinants on perceptual learning. Previous studies revealed that lower vertical gradients produce higher amplitudes in ERP components (N170) (Li, Jia, Chung-Fat-Yim, Jin, & Yu, 2017) and lower omega complexity, which assesses global synchronization between spatially distributed brain areas (Li, Jia, & Yu, 2017). Our findings show that lower vertical disparity gradients produce more sensitive and stable double fusion results, suggesting that the sensitivity and stability of double fusion may relate to ERP components and omega complexity.

### 5 Conclusion

This study provides evidence demonstrating the relationship between perceptual learning and two determinants in stereopsis—vertical disparity gradient and cue conflict. Results revealed that for each level of these factors, RTs for double fusion decreased while duration increased with each training session. Moreover, vertical disparity gradient and cue conflict affected RTs and duration of double fusion, and the interaction between vertical gradient and cue conflict was significant. These findings suggest that perceptual learning occurs for each level of

the two determinants in stereopsis and that these factors jointly influence perceptual learning. Consequently, perceptual learning can improve the sensitivity and stability of double fusion in monocular occlusion.

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### Figure Legends

**Figure 1.** An example of monocular occlusions. The nearer surface differentially occludes the more distant surface in the two eyes, generating features visible to only one eye. Red lines delimit regions of the more distant surface visible to the left eye; blue lines delimit regions visible to the right eye.

**Figure 2.** A schematic representation of Panum's limiting case from an arrangement of two real objects. The closer cube occludes the more distant cube for the left eye, but both cubes remain visible for the right eye. In this situation, the image presented to the left eye shows only one cube (since the two cubes are superimposed), while the image presented to the right eye shows two cubes at different locations. The stimulus below each eye depicts the image presented to that eye's perspective.

**Figure 3.** An example of the stimulus used in this experiment. When a single straight line is presented to the left eye and two curved lines to the right eye, observers perceive the left 3D feature as closer than the right feature after binocular fusion. Other stimuli varied by different vertical disparity gradients (0.1, 0.3, and 0.6) and cue conflict levels (low, medium, and high) based on this configuration.

**Figure 4.** Sequence of events within each trial. At trial onset, a reference plane consisting of two rectangles appeared for unlimited time. When observers perceived the two rectangles fused into a single stable rectangle, they pressed the 'Space' key. The stimulus then appeared for 10 seconds, during which observers reported their perception of double fusion or other percepts (single fusion, diplopia, or binocular rivalry).

**Figure 5.** RT results for vertical disparity gradient and cue conflict. The Y-axis represents RT values for reported double fusion. Within each figure, the three column groups from left to right represent the three vertical gradient levels (0.1, 0.3, and 0.6). Within each group, the three colored columns represent low, medium, and high cue conflict, respectively. Error bars represent standard errors of the means (SEM).

**Figure 6.** RT results for vertical disparity gradient and training. The X-axis represents the five training sessions across three vertical gradient levels. Green, orange, and blue lines represent RTs for 0.1, 0.3, and 0.6 vertical disparity gradient, respectively. Error bars show 95% confidence intervals.

**Figure 7.** RT results for cue conflict and training. The X-axis represents the five training sessions across three conflict levels. Green, orange, and blue lines represent RTs for low, medium, and high conflict, respectively. Error bars show 95% confidence intervals.

**Figure 8.** Duration results for double fusion across vertical disparity gradient and cue conflict. The Y-axis represents duration of reported double fusion. Other legends are identical to Figure 5.

**Figure 9.** Duration results for double fusion across vertical gradient and training. Other legends are identical to Figure 6.

### Figures

- Figure 1.
- Figure 2.
- Figure 3.
- Figure 4.
- Figure 5.
- Figure 6.
- Figure 7.
- Figure 8.
- Figure 9.

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