

---

# Ecologically invalid monocular texture leads to longer perceptual latencies in random-dot stereograms

---

Philip M Grove<sup>¶</sup>, Hiroshi Ono

Centre for Vision Research, York University, Toronto, Ontario M3J 1P3, Canada;  
e-mail: [philg@yorku.ca](mailto:philg@yorku.ca)

Received 4 August 1998, in revised form 22 December 1998

---

**Abstract.** Two experiments were conducted to explore Gillam and Borsting's (1988, *Perception* 17 603–608) report that uncorrelated monocular texture facilitates stereopsis by shortening the latency to see depth in random-dot stereograms. Experiment 1 used stereograms similar, in pattern but not disparity, to Gillam and Borsting's with monocular texture present or absent. A third condition, where monocular texture was dissimilar to the binocular panels and background, was also used. We were unable to generalize the findings of Gillam and Borsting for a depth step of 6 min of arc to a larger depth step of 24 min of arc. That is, we observed no significant difference in latencies between the conditions with monocular texture absent and present at a disparity of 24 min of arc. We found latencies to be significantly longer in the monocular-texture-different condition than the monocular-texture-absent condition, however. We account for this, ad hoc, by arguing that the monocular-texture-different stereogram depicts a rare or 'accidental' visual scenario. This account was supported by the results of experiment 2 which showed that stereograms depicting accidental views yielded longer latencies than those depicting generic views. We conclude that the ecological validity of monocular texture must also be considered when assessing the effects of monocular texture on stereopsis.

## 1 Introduction

Humans are frontal-eyed animals with a large binocular field. As a result, each eye gets a slightly different view of the world and we are, therefore, able to take advantage of retinal disparity to create a three-dimensional representation of our surroundings. One notable feature resulting from the lateral separation of our two eyes is that opaque objects and surfaces occlude other objects and surfaces to different extents in the two eyes. Regions, resulting from differential occlusion, that are only visible to one eye are called monocular occlusion zones.

Monocular occlusion zones have been a puzzle for existing models of stereopsis because they contain features present in one eye's image which cannot be matched in the other eye's image. Many existing theories of stereopsis require features in one eye's image, be they individual points (Dev 1975; Julesz 1971; Marr and Poggio 1976; Sperling 1970), edges (Marr 1982; Marr and Poggio 1979), or patches of varying size (Geiger et al 1993; Gruen 1985; Kanade and Okutomi 1990), to be matched with a corresponding feature in the other eye's image and their relative positions on the retinas ascertained to recover depth. The above models do not address the role of monocular regions in stereopsis, yet recent studies have reported that monocular features have a marked effect on stereopsis (see eg Anderson 1994; Anderson and Nakayama 1994; Kaufman 1965; Nakayama and Shimojo 1990a; Shimojo and Nakayama 1990, 1994).

Gillam and Borsting (1988) propose that uncorrelated monocular texture in random-dot stereograms facilitates stereopsis. This is an interesting claim since it is counter-intuitive to expect that additional monocular detail would aid a binocular process. The authors measured the latency to see depth in random-dot stereograms depicting two rectangular surfaces such that the surface on the left appeared at a different depth from

---

<sup>¶</sup> Send correspondence to: Philip Grove, ATR Human Information Processing Research Laboratories, 2-2 Hikaridai, Seika-cho Souraku-gun, Kyoto 619-0288, Japan

the one on the right. The authors report shorter latencies for random-dot stereograms with monocular texture similar to the binocular panels than when the monocular region was blank, suggesting that uncorrelated monocular texture facilitates stereopsis.

Howard and Rogers (1995) reviewed this paper and pointed out that, in Gillam and Borsting's condition where the monocular zone was filled with texture, it was similar to the far surface. When the monocular texture was absent, the monocular region was different from the far surface. Howard and Rogers propose that the crucial factor accounting for the different latencies in these two conditions may have been the similarity of the monocular region to the far surface. They recommend a control experiment where the monocular zone is filled with texture different from the far surface and the background. In the present study, we compared latencies for three conditions: monocular texture absent, monocular texture present and similar to the binocular panels, and monocular texture present and different from the binocular panels and background. If monocular texture by itself facilitates stereopsis, which we infer from Gillam and Borsting's report, we expect the latencies in both the condition with monocular texture present and same and the condition with monocular texture present and different to be significantly shorter than the monocular-texture-absent condition. If, however, the crucial factor is the similarity of the monocular texture to the far surface, as proposed by Howard and Rogers, we expect latencies in the monocular-texture-present condition to be significantly shorter than the monocular-texture-absent and monocular-texture-different conditions.

## 2 Experiment 1

The first experiment addressed the alternative suggestions of Gillam and Borsting (1988) and Howard and Rogers (1995). We measured the time required to correctly identify the relative depth of two adjacent frontoparallel planes, presented at disparity of 24 min of arc<sup>(1)</sup> for three monocular-texture conditions. In the first condition, the monocular texture was absent, in the second the monocular zone was filled with texture similar to the binocular panels, and in the third the monocular zone was filled with texture dissimilar to the binocular panels and the background. In short, we measured the time required to correctly detect the relative depth in a random-dot stereogram with uncorrelated monocular texture absent, present, or present and different from the binocular panels and background.

### 2.1 Method

2.1.1 *Observers.* Twelve observers from the York University community, reporting normal or corrected-to-normal binocular vision, participated. All observers were naive as to the purpose of this experiment.

<sup>(1)</sup> The disparity of 24 min of arc was chosen for this experiment on the basis of the results of experiment 1 of Philip Grove's MA thesis (Grove 1997). The purpose of that experiment was to assess the different suggestions of Gillam and Borsting (1988) and Howard and Rogers (1995) and to extend the investigation to include larger disparities. Seven observers, six of whom were experienced in psychophysical experiments, participated. The procedure for this experiment paralleled the one outlined in experiment 1 of the present paper. In this experiment, however, observers viewed 144 stimuli [3 monocular-texture conditions  $\times$  4 disparities (6, 12, 18, 24 min of arc)  $\times$  2 depth orders  $\times$  6 presentations]. Latencies of the six experienced observers, for the monocular-texture-absent and monocular-texture-same conditions, were all under 1 s with no significant difference between conditions. For four of the seven observers, however, latencies tended to be longer in the monocular-texture-different condition at larger disparities. A floor effect was suspected in the experiment just described. We addressed this possibility (Grove 1997) by reducing the contrast of the random-dot stereograms, which increased the perceptual latency in all conditions. Still, we were unable to detect a difference in stereo latency between monocular-texture conditions. Experiment 1, in the present study, was carried out to explore these findings in more detail. Philip Grove's MA thesis is a public document available on request from him or the York University Department of Psychology Resource Centre.

2.1.2 *Stimuli.* Random-dot stereograms were generated on a Macintosh II computer and presented on two Macintosh 14 inch Color Plus monitors, viewed in a haploscope at a distance of 80 cm. Both computer screens were cropped by an opaque rectangular aperture, attached to the front of the computer screens. Each aperture subtended 12.1 deg vertically and 16 deg horizontally. We generated random points to fill a field 15 cm  $\times$  15 cm, subtending 10.7 deg. Each dot subtended 1.5 min of arc. To ensure that the generated field had a uniform density, a pseudorandom technique was employed. This entailed dividing the 15 cm  $\times$  15 cm field into sixteen smaller cells which were then filled with random dots with a density of 1%. The density of 1% was defined such that for every 100 pixels on the computer screen, 99 were colored white and one was colored black.

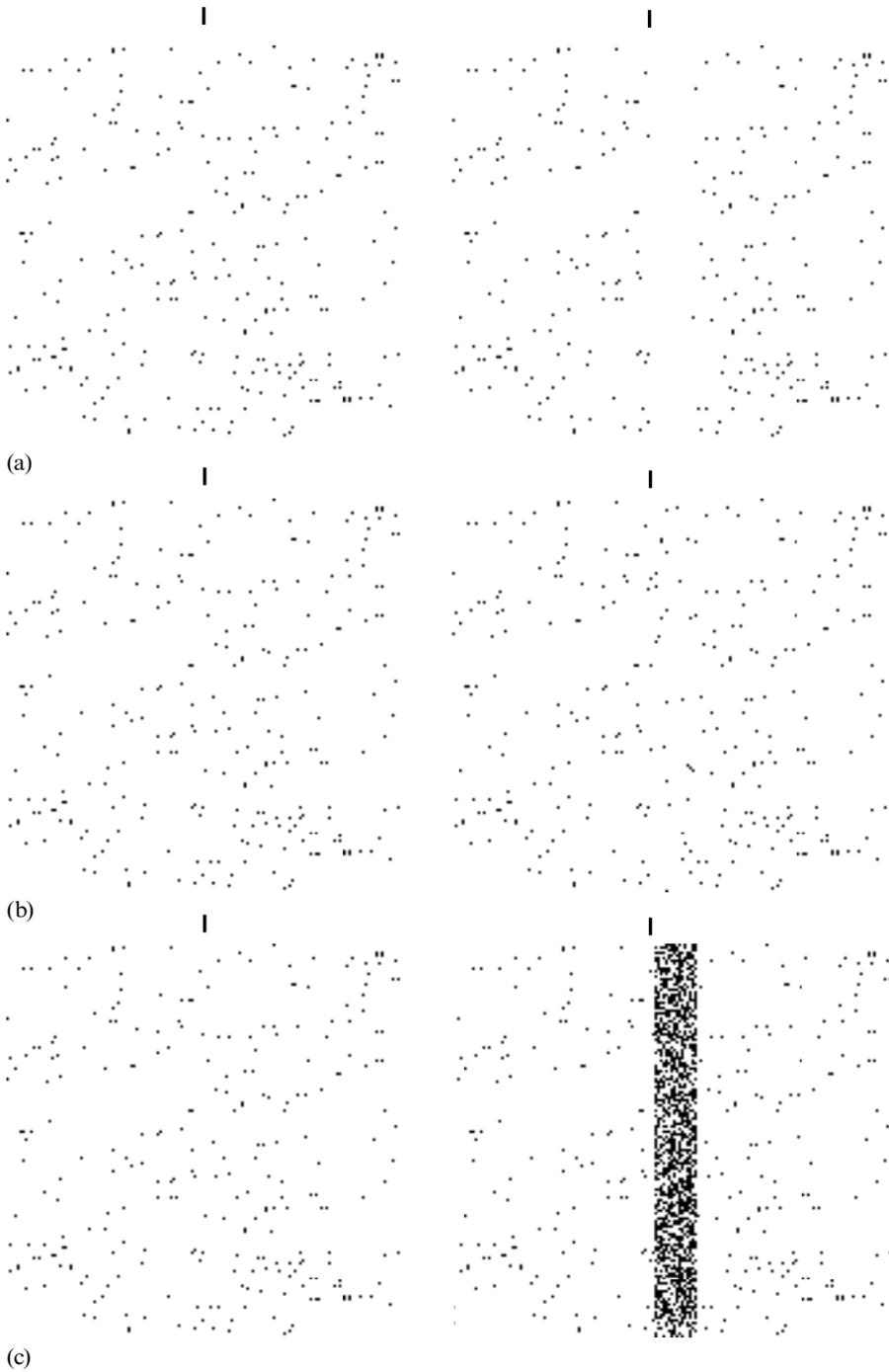
One reviewer questioned whether the density of our random-dot stereograms was similar to the density of Gillam and Borsting's. We constructed our stereograms by adhering as closely as possible to the specifications outlined by Gillam et al (1988). In that paper, they describe the procedure for generating their stereograms as follows:

"Stereograms were produced by generating random points to fill a 1200  $\times$  1200 field ... In order to guarantee that the generated field would have a uniform density of points, a pseudorandom technique was used. The 1200  $\times$  1200 field was divided into 100 square boxes of 120  $\times$  120. Twelve dots were then placed randomly inside each box" (page 174).

We compared our stimulus with the figures in Gillam and Borsting's paper and were satisfied that the stereograms in the two studies were of similar density. These stereograms when fused gave the percept of two rectangular planes, such that the plane on the left appeared at a different depth from the one on the right. In all stereograms, disparity was introduced by laterally shifting one of the rectangular dot panels in one eye's image. The space that was left by this lateral shift was the monocular zone. In the first type of stereogram this space was left blank, in the second this space was filled with dots with a density of 1%, according to the definition above. In the third type of stereogram the monocular zone was filled with dots with a density of 50%. That is, for every 100 pixels in the monocular zone, 50 were colored black and 50 were colored white. These corresponded to the monocular-texture-absent, monocular-texture-same, and monocular-texture-different conditions, respectively, and are depicted in figure 1.

2.1.3 *Procedure.* All experiments were conducted in a dark room. Three computer displays provided the only ambient light. Observers were seated in front of the stereoscope with their chin in a chin rest to maintain constant viewing distance. All experiments began with a preliminary series of trials intended to train observers to establish their vergence on or near the stimulus plane. This was done for two reasons: first, to make sure that directing one's gaze at the intersection of the fixation cross did, in fact, establish one's vergence near the stimulus plane; second, to illustrate to inexperienced observers the requirement of fixating right at the intersection of the cross.

In these training runs, observers were told to look directly at the center of a zero-disparity fixation cross until they were confident their gaze was directed right at the intersection of the vertical and horizontal lines. At this point, the observer depressed a button which elicited the presentation of a pair of Nonius lines replacing the fixation cross. Each of the Nonius lines, which were centered on the intersection of the fixation cross and subtended 3 min of arc horizontally and 60 min of arc vertically, were presented for 500 ms and then replaced by the zero-disparity fixation cross. Observers could repeat this procedure as many times as they wished. After a few preliminary trials, observers were shown a number of diagrams depicting Nonius lines that were offset by various amounts, ranging from perfectly aligned to misaligned by 6 line widths (equal to a misconvergence of 18 min of arc). Observers were asked to match their percept with one of the diagrams. All twelve observers met the criterion



**Figure 1.** Stereograms used in experiment 1: (a) monocular zone blank, (b) monocular zone similar, and (c) monocular zone different. With cross fusion, the panel on the right should appear closer than the panel on the left. Images have been cropped for this figure to 37.5% of the original horizontal and vertical dimensions. See text for details.

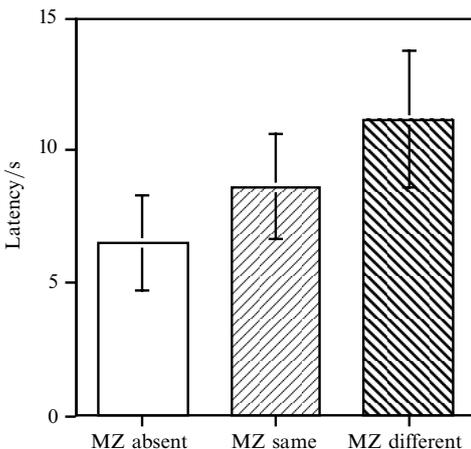
that the Nonius lines should not be misaligned by more than 2 line widths (equal to a misconvergence of 6 min of arc). Once observers were comfortable with this procedure, they were instructed to proceed with ten more practice trials and report any trials where the Nonius lines were misaligned by a noticeable amount.

In order to ensure that all observers were sufficiently familiar with the stereo task, they were told that they would be viewing random-dot stereograms depicting two rectangles at different depths. Observers were told that the rectangles were equal halves of a square region of random dots. To further familiarize the observers without allowing them to practice the stereo task (which was undesirable in this experiment), they were directed to look at one of the computer monitors where a 'no-shift' half image was presented and the above explanation was repeated. The experimenter continued to familiarize each observer until both he and the observer were confident that the experimental task was fully understood. This proved to be a successful strategy as observers made very few errors.

In the experiment proper, observers directed their gaze at the center of the cross. When the stimulus was ready for presentation a tone sounded, signaling to the observer to press a button to elicit the stereogram. The timer started when the stereo half images appeared on the screens. When the observer could identify two distinct rectangles and was sure of the depth order between them, he/she pressed the button again, stopping the timer, extinguishing the stereograms, and returning the fixation cross to the screens. Latency was measured as the time interval between the appearance of the stereograms and the button press that extinguished them. Observers verbally reported the depth order to the experimenter and were instructed not to guess. If an error was made, that trial was discarded and repeated at the end of the block. Seven observers performed perfectly, while five observers made two errors out of thirty-six trials. Each stimulus was presented six times, in random order, for a total of thirty-six trials (3 monocular texture stereograms  $\times$  2 depth orders  $\times$  6 presentations).

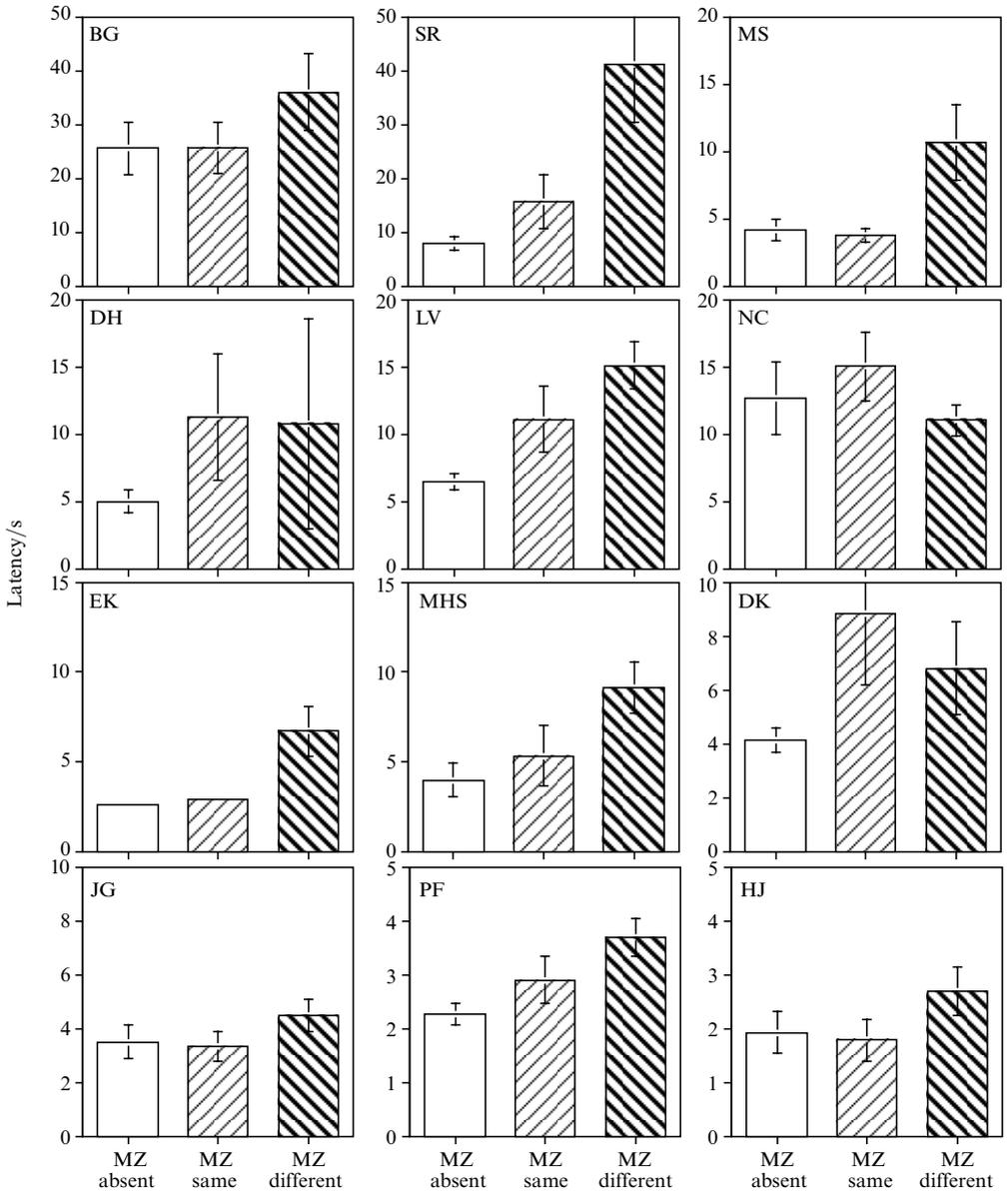
## 2.2 Results and discussion

Group means, based on twelve observations by each observer for each monocular-texture condition (6 presentations  $\times$  2 depth orders), are presented in figure 2. Group data were analyzed by using an analysis of variance with repeated measures and the Greenhouse–Geisser critical  $F_{1,11}$ . This revealed a significant effect of monocular texture on the latency of stereopsis ( $F_{1,11} = 10.21$ ,  $p < 0.01$ ). With only three means to compare, the Newman–Keuls analysis was an appropriate a posteriori test (Howell 1992). Latencies, in seconds, in the monocular-texture-different condition (mean = 11.15, SD = 8.96) were significantly longer than the monocular-texture-absent condition (mean = 6.49, SD = 6.13;



**Figure 2.** Mean latencies,  $\pm$  standard error, of twelve observers' data based on twelve observations each for each of the three monocular zone (MZ) conditions: MZ absent, MZ same, MZ different. See text for details.

$p < 0.01$ ), and the monocular-texture-same condition (mean = 8.61, SD = 6.92;  $p < 0.05$ ). Latencies in the monocular-texture-same and the monocular-texture-absent conditions were not significantly different, however. One reviewer pointed out that the lack of significant difference in latencies between the monocular-texture-absent condition and monocular-texture-same condition could be due to the low texture density of our stereograms and may not be generalizable to stereograms with higher dot density. This same reviewer suggested and accepted a supplementary analysis of our data, from identical stereograms, which agreed with Gillam and Borsting's (1988) report, however (see footnote 3).



**Figure 3.** Individual data plots,  $\pm$  standard errors, for the twelve observers of experiment 1. Each bar represents twelve observations for each of the three monocular zone (MZ) conditions: MZ absent, MZ same, MZ different. Note: owing to individual differences, the y-axis scales of the individual graphs differ.

Individual data, presented in figure 3, support the group analysis. For nine of the twelve observers, the latency for stereopsis was longer in the monocular-texture-different condition than in the monocular-texture-absent or monocular-texture-same conditions. Of the three observers who did not show this trend, one observer's latencies in the monocular-texture-different condition were only slightly shorter than in the monocular-texture-same condition. Furthermore, only three observers showed tendencies resembling those reported by Gillam and Borsting. That is, latencies in the monocular-texture-same condition were shorter than in the monocular-texture-absent condition. These differences were very small, however.

These results appear inconsistent with both Gillam and Borsting's and Howard and Rogers's hypotheses. The two conditions analogous to Gillam and Borsting's (1988) stimuli, monocular texture absent and monocular texture same, did not give the same pattern of latencies reported by those authors. Latencies for stereograms with monocular texture that was the same as the binocular panels were not significantly different from the latencies for the monocular-texture-absent stereograms. The longer latency observed in the monocular-texture-different condition appeared to be compatible with Howard and Rogers's suggestion. However, there was no corresponding long latency observed for the monocular-texture-absent condition in the group-data analysis. In fact only three of the twelve observers showed a pattern resembling the one predicted by Howard and Rogers. The data presented above do not support Gillam and Borsting's claim that monocular texture, by itself, facilitates stereopsis nor Howard and Rogers's suggestion that the similarity of the monocular zone to the far surface is the crucial factor determining the relative latencies in the monocular-texture-absent condition and the monocular-texture-present condition.

One possible reason for our failure to replicate the original finding of Gillam and Borsting (1988) is that the disparity in the above experiment was 24 min of arc, as opposed to 6 min of arc for which the authors reported significant differences in latencies between monocular-texture conditions. We conducted three studies prior to the present experiment involving a depth step of 6 min of arc and the three monocular-texture conditions. We were unable to find a stimulus condition where we could reliably reproduce the findings reported by Gillam and Borsting. We did observe similar trends to those in Gillam and Borsting's report when we repeated their experimental protocol<sup>(2)</sup> with disparity of 6 min of arc (Grove 1997). Our statistical analysis did not reveal significant differences in latencies between monocular-texture conditions, however,<sup>(3)</sup>

<sup>(2)</sup> In this experiment, we adhered to Gillam and Borsting's (1988) experimental procedure as closely as possible and addressed the alternative suggestions of these authors and Howard and Rogers (1995). Twenty-one naive observers, reporting normal binocular vision, viewed identical stereograms to the ones used in experiment 1, presented with a disparity of 6 min of arc. The procedure was identical to experiment 1 with one exception. Each observer viewed a total of six stimuli (1 presentation  $\times$  2 depth orders  $\times$  3 monocular-texture stereograms). In Gillam and Borsting's study, observers viewed a total of four stimuli [1 presentation  $\times$  depth orders  $\times$  2 monocular-texture conditions (Grove 1997)].

<sup>(3)</sup> An analysis of variance with repeated measures, with the Greenhouse–Geisser critical  $F_{1,20}$ , performed on the mean latencies of twenty-one observers, failed to reveal a significant effect for monocular texture ( $F_{1,20} = 3.95$ ,  $p = 0.055$ ). In response to a suggestion from an anonymous reviewer, however, we compared the means of a subset of our data, the monocular-texture-absent and monocular-texture-same conditions with a one-tailed paired  $t$ -test, the same analysis used by Gillam and Borsting. This test yielded  $t_{20} = 1.815$ ,  $p = 0.0423$ . Gillam and Borsting (1988) report a significant difference between monocular-texture-absent and monocular-texture-present conditions based on data from fourteen observers ( $t_{13} = 3.43$ ,  $p < 0.005$ ). This discrepancy does not affect the main argument of the present paper, however, since our primary concern in this paper is the results pertaining to a depth step of 24 min of arc. Why we cannot reliably reproduce Gillam and Borsting's results with a depth step of 6 min of arc in Grove's (1997) experiments 1 and 2 is still a puzzle to us.

and we have chosen to refrain from making inferences based on these data (see McNemar 1955, page 70). Furthermore, we have discussed the present findings with Dr Gillam and could find no anomalies in our stimuli or procedures to account for our different results at larger disparities. We have chosen to pursue the phenomenon presented here rather than tracking down a stimulus which reliably produces the latency patterns reported by Gillam and Borsting. Our inability to obtain a pattern of results similar to Gillam and Borsting's with a depth step of 24 min of arc remains a mystery to us.

Nevertheless, the data from the present experiment do show that the type of texture contained in a monocular region, at a disparity of 24 min of arc, has a significant effect on the latency for stereopsis, as illustrated by the latencies in the monocular-texture-different condition.

Let us examine the monocular-texture-different condition more closely. The density of the dots in the monocular zone of this condition was many times greater than that of the binocular panels. This stimulus generates a rather unusual percept where the far surface appears to change its texture right at the point where that surface is occluded to one eye. We argue that the percept generated by this stimulus corresponds to what Nakayama and Shimojo (1990b, 1992) call an 'accidental' view. That is, of all the surface configurations that the visual system is likely to encounter, the one depicted by the monocular-texture-different condition represents a very small minority. The novel appearance of this stimulus may account for the longer perceptual latencies observed in this condition compared with the monocular-texture-absent and monocular-texture-present conditions. In relative terms, the percept generated by the monocular-texture-different condition, the texture of a far surface changing right at the point where it becomes occluded to one eye, can be thought of as an accidental view compared with the more 'generic' views depicted by the monocular-texture-absent and monocular-texture-present conditions, showing two distinct rectangular planes separated in depth against a white background and a near rectangle occluding a far rectangle which continues behind the near one, respectively. This will be discussed in more detail in section 4.

This is purely an ad hoc account of the data. To test this account we next manipulated the type of view depicted by stereograms containing dense or sparse monocular texture to see if the view generated by a stereogram, accidental or generic, had an impact on the latency to see depth.

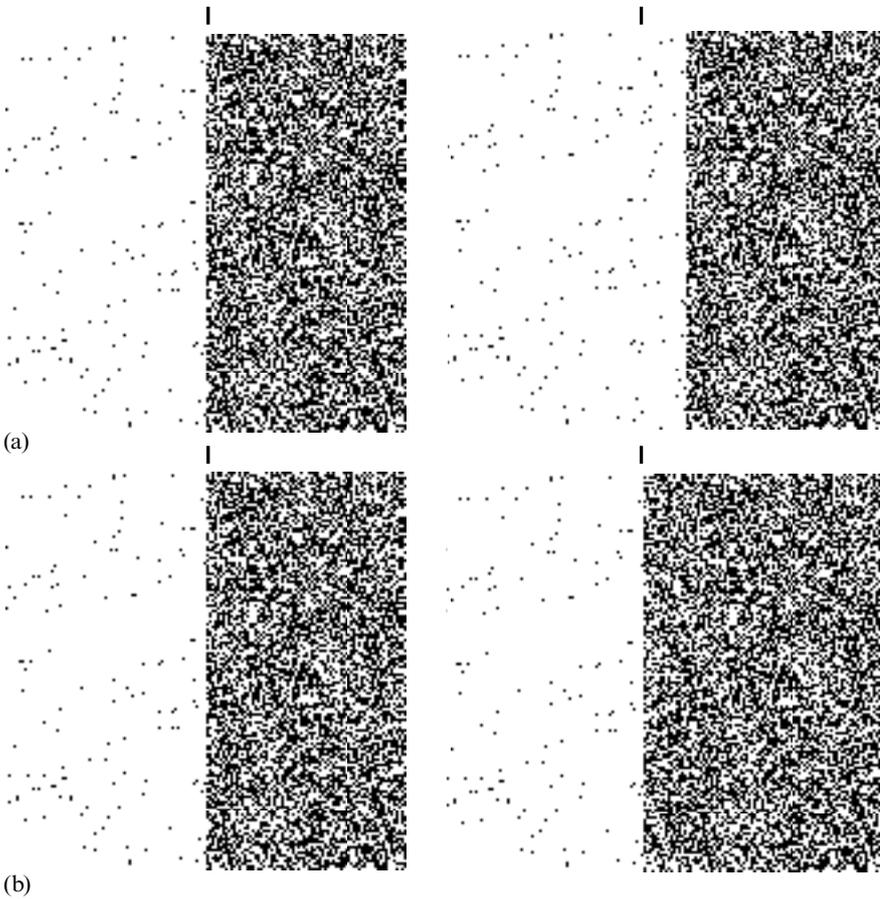
### 3 Experiment 2

This experiment measured the latency of stereopsis in stereograms depicting an accidental or a generic view.

#### 3.1 Method

3.1.1 *Observers.* Ten observers from the York University community, reporting normal or corrected-to-normal binocular vision, participated. All observers were naive as to the purpose of the experiment.

3.1.2 *Stimuli.* We generated new stereograms where the monocular texture could be made accidental or generic by manipulating the depth order between the two adjacent panels. To do this, we simply increased the dot density of one of the binocular panels to 50%. See figure 4 for two examples. Observers saw two distinct rectangles, one that was very sparse (1% dot density) and one that was considerably more dense (50% dot density). The side on which each panel appeared was changed between blocks. There were two types of monocular texture used in this experiment, 1% and 50% dot density. When the sparse panel appeared further away than the dense panel, the sparse monocular texture was the appropriate, or generic, match for the far panel while the dense monocular texture was inappropriate or accidental. Conversely, if the dense panel was further away, the dense monocular texture was an appropriate match for the



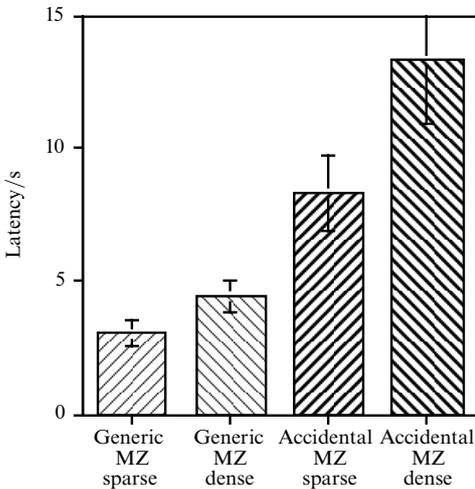
**Figure 4.** Stereograms used in experiment 2. With cross fusion, the panel on the right should appear closer than the panel on the left. The monocular region was filled with texture that was similar to the far plane (generic view) as in (a) or different from the far plane (accidental view) as in (b). Images have been cropped for this figure to 37.5% of the original horizontal dimension and vertical dimensions. See text for details.

far panel while the sparse monocular texture was an inappropriate match. In short, a stereogram depicted a generic view if the monocular texture matched the texture of the far plane and depicted an accidental view if the monocular texture did not match the far plane. In total, four stereograms were generated: two generic stereograms, one with a sparse far panel and matching monocular texture, the second with a dense far panel and matching monocular texture; two accidental stereograms, one with a dense far panel and sparse monocular texture, the second with a sparse far panel and dense monocular texture. Each observer completed forty-eight trials (4 stereograms  $\times$  2 depth orders  $\times$  6 presentations).

3.1.3 *Procedure.* The procedure was the same as experiment 1.

### 3.2 Results and discussion

Group means, based on twelve observations, of each stereogram by each observer, are presented in figure 5. Group data were analyzed by using an analysis of variance with repeated measures and the Greenhouse–Geisser critical  $F_{1,9}$ . This analysis revealed a significant effect of monocular texture on the latency of stereopsis ( $F_{1,9} = 15.87$ ,  $p < 0.01$ ). Newman–Keuls a posteriori analysis revealed that the



**Figure 5.** Mean latencies,  $\pm$  standard error, of ten observers' data based on twelve observations each for each of the four monocular zone conditions: generic monocular texture dense (Generic MZ dense), generic monocular texture sparse (Generic MZ sparse), accidental monocular texture sparse (Accidental MZ sparse), accidental monocular texture dense (Accidental MZ dense).

accidental-monocular-texture-dense condition (mean = 13.35, SD = 7.74) yielded latencies significantly longer than the three other conditions; namely, generic monocular texture sparse (mean = 2.98, SD = 1.54;  $p < 0.01$ ), generic monocular texture dense (mean = 4.41, SD = 1.87;  $p < 0.01$ ), and accidental monocular texture sparse (mean = 8.28, SD = 4.47;  $p < 0.01$ ). The accidental-monocular-texture-sparse condition yielded latencies significantly longer than the generic-monocular-texture-sparse ( $p < 0.01$ ), and the generic-monocular-texture-dense ( $p < 0.05$ ) conditions.

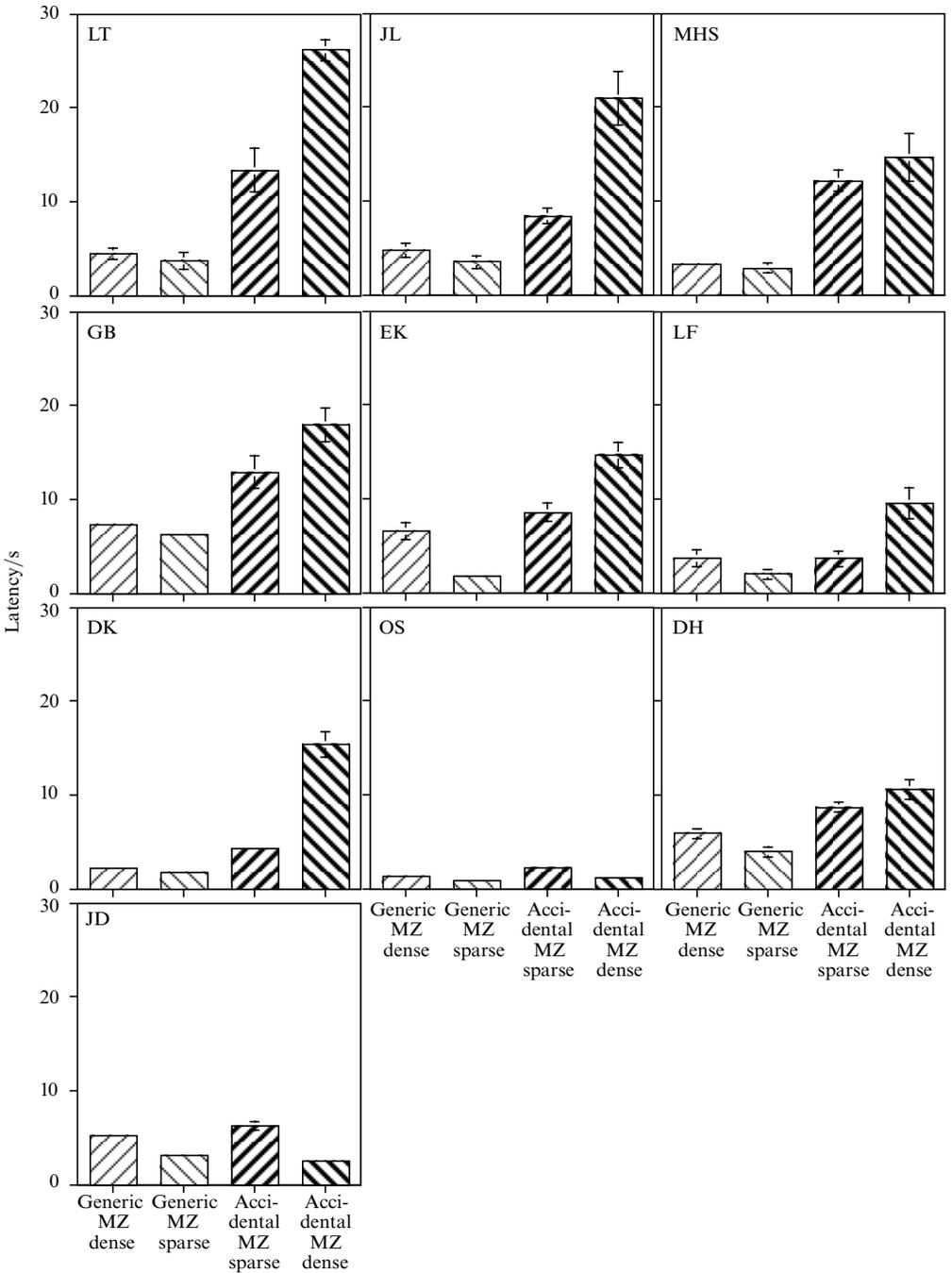
An inspection of the individual data, presented in figure 6, reveals the same trend as for the group data. Eight of the ten observers exhibit the same ordinal relation among the four monocular-texture conditions. Furthermore, nine of the ten observers showed longer latencies in the accidental-monocular-texture-sparse condition than in the generic-monocular-texture-dense or generic-monocular-texture-sparse conditions. The data from 80% of the observers showed longer latencies for stereograms depicting accidental views than those depicting generic views.

Therefore, stereograms depicting accidental views took significantly longer to see than stereograms depicting generic views. The data reported in experiment 2 support the ad hoc hypothesis of the data reported in experiment 1. It seems that the latency for stereopsis in these types of stereograms depends on the global percept generated by the stereograms. That is, latency is dependent on the generic or accidental nature of the percept.

#### 4 General discussion

In experiment 1, latencies in the monocular-texture-different condition were significantly longer than in both the condition with the monocular texture absent and in the condition with the monocular texture present and similar. We can account for this pattern of latencies by assessing the probability of each set of images arising from a particular scene. Nakayama and Shimojo (1990b, 1992) elaborated on these conditional probabilities by borrowing two terms from Richards et al (1987) and Koenderink (1990), the generic and accidental views. Simply put, the visual system is reluctant to make 'inferences' based on assumptions that are highly improbable. Generic views are analogous to the veridical candidates that are most commonly encountered by the visual system and are the interpretations it chooses, given stimuli with two or more possible interpretations.

In experiment 1, the disparity information indicated a rectangular panel in front of another surface. The absence, presence, or type of monocular texture corresponded to very different real-world configurations, however, some very common and others



**Figure 6.** Individual data plots,  $\pm$  standard errors, for the ten observers of experiment 2. Each bar represents twelve observations for each of the four monocular-texture conditions: generic monocular texture dense (Generic MZ dense), generic monocular texture sparse (Generic MZ sparse), accidental monocular texture sparse (Accidental MZ sparse), accidental monocular texture dense (Accidental MZ dense).

relatively rare. The shorter latencies observed in the conditions with monocular texture absent and with monocular texture present and similar relative to the monocular-texture-different condition were analogous to the visual system choosing Nakayama and Shimojo's (1990b, 1992) generic view over an interpretation based on an accidental view. The monocular-texture-different condition of experiment 1 depicted two surfaces separated in depth where the far surface abruptly changed, at the point where it was occluded to one eye, to a texture that was very different from the binocular portion of the far surface. While this situation is possible, it is rather improbable compared with the surface configuration depicted by the other two conditions. In relative terms, the surface configurations most likely to be anticipated by the visual system were those that were seen fastest. These were the conditions with the monocular texture absent and monocular texture present, which depicted two rectangles in depth with no occlusion, or a rectangle occluding a farther surface with uniform texture, respectively. Therefore, monocular texture dissimilar to both the binocular panels and the background may be perceived as an unlikely spatial configuration, analogous to Nakayama and Shimojo's accidental view (1990b, 1992). Since the visual system is reluctant to make inferences based on accidental views, the longer latencies may be attributable to the visual system looking for alternate interpretations of the stimuli. This agrees with observers' subjective reports of 'being less sure' of the depth order in the monocular-texture-different condition.

Experiment 2 followed up this analysis by using different stimuli and showed that depth was seen faster in stereograms which generated a generic view than those depicting an accidental view. Latencies to see depth were significantly shorter in those stereograms where monocular texture matched the far surface (generic view) than in stereograms where the monocular texture did not match the far surface (accidental view). The data from these experiments suggest that monocular texture impedes stereopsis when it does not match the texture of the far surface or is out of context with the global percept.

The data presented here suggest that there is more to be said about the role of monocular texture in stereopsis. It seems that the effect of monocular texture on stereopsis is more complicated than either Gillam and Borsting (1988) or Howard and Rogers (1995) have suggested. This study has shown that monocular texture, when ecologically valid, leads to shorter latencies to see depth, but that same monocular texture, when put in a different context, can retard stereopsis as well. Therefore, questions about the ecological validity of monocular texture, such as whether an accidental or generic view is depicted in a stimulus, should be considered first when assessing the effect of monocular texture on stereopsis.

Our aim here has not been to contradict the claims of Gillam and Borsting or Howard and Rogers. Rather, we hope to stress that accounting for the role of monocular occlusion zones in stereopsis is a more complicated task than we, or previous researchers, had anticipated. In fact, we feel that our ecological analysis complements the recent work of Nakayama and Gillam (1998) and Gillam and Cook (1998).

**Acknowledgements.** Experiment 1 of this study was part of Philip Grove's MA thesis. We wish to thank his supervisory committee members, Martin Steinbach, Laurie Wilcox, and examining committee members, Doug Crawford and Brock Fenton, for their helpful comments on this experiment, and Makoto Ichikawa for writing the computer programs for the stimuli used in these experiments. We also wish to thank the anonymous reviewers for their comments on an earlier version of this paper. The final version of this paper was prepared by both authors at ATR Human Information Processing Laboratories, Kyoto, Japan. This research was supported by Grant A0296 from the Natural Sciences and Engineering Research Council of Canada.

---

**References**

- Anderson B, 1994 "The role of partial occlusion in stereopsis" *Nature (London)* **367** 365–368
- Anderson B, Nakayama K, 1994 "Toward a general theory of stereopsis: binocular matching, occluding contours, and fusion" *Psychological Review* **101** 414–445
- Dev P, 1975 "Perception of depth surfaces in random-dot stereograms: a neural model" *International Journal of Man – Machine Studies* **7** 511–528
- Geiger D, Ladendorf B, Yuille A L, 1993 "Occlusions and binocular stereo", technical report 93-1, Harvard Robotics Laboratory, Harvard University, Cambridge, MA
- Gillam B, Borsting E, 1988 "The role of monocular regions in stereoscopic displays" *Perception* **17** 603–608
- Gillam B, Chambers D, Russo T, 1988 "Postfusional latency in slant perception and the primitives of stereopsis" *Journal of Experimental Psychology: Human Perception and Performance* **14** 163–175
- Gillam B, Cook M L, 1998 "Binocular depth from unpaired intrusions" *Investigative Ophthalmology & Visual Science* **39**(4) S669
- Grove P M, 1997 *The Role of Monocular Zones in Stereopsis* MA thesis, York University, Toronto, Canada
- Gruen A W, 1985 "Adaptive least squares correlation: a powerful image matching technique" *South African Journal of Photogrammetry, Remote Sensing and Cartography* **14** 175–187
- Howard I P, Rogers B J, 1995 *Binocular Vision and Stereopsis* (Oxford: Oxford University Press)
- Howell D C, 1992 *Statistical Methods for Psychology* 3rd edition (North Scituate, MA: Duxbury Press)
- Julesz B, 1971 *Foundations of Cyclopean Perception* (Chicago, IL: Chicago University Press)
- Kanade T, Okutomi M, 1990 "A stereomatching algorithm with an adaptive window: theory and experiments", in *Proceedings of the Image Understanding Workshop* (Washington, DC: DARPA, Science Application, Inc)
- Kaufman L, 1965 "Some new stereoscopic phenomena and their implications for the theory of stereopsis" *American Journal of Psychology* **78** 1–20
- Koenderink J J, 1990 *Solid Shape* (Cambridge, MA: MIT Press)
- McNemar Q, 1955 *Psychological Statistics* 2nd edition (New York: John Wiley)
- Marr D, 1982 *Vision* (New York: W H Freeman)
- Marr D, Poggio T, 1976 "Cooperative computation of stereo disparity" *Science* **194** 283–287
- Marr D, Poggio T, 1979 "A computational theory of human stereo vision" *Proceedings of the Royal Society of London, Series B* **204** 301–328
- Nakayama K, Gillam B, 1998 "Four types of stereoscopic depth from unpaired image regions: a taxonomy based on border ownership assignments" *Investigative Ophthalmology & Visual Science* **39**(4) S669
- Nakayama K, Shimojo S, 1990a "Da Vinci stereopsis: depth and subjective contours from unpaired image points" *Vision Research* **30** 1811–1825
- Nakayama K, Shimojo S, 1990b "Toward a neural understanding of visual surface representation" *Cold Spring Harbour Symposia in Quantitative Biology* **55** 911–923
- Nakayama K, Shimojo S, 1992 "Experiencing and perceiving visual surfaces" *Science* **257** 1357–1363
- Richards W A, Koenderink J J, Hoffman D D, 1987 "Inferring three dimensional shapes from two dimensional silhouettes" *Journal of the Optical Society of America A* **4** 1168–1175
- Shimojo S, Nakayama K, 1990 "Real world occlusion constraints and binocular rivalry" *Vision Research* **30** 69–80
- Shimojo S, Nakayama K, 1994 "Interocularly unpaired zones escape binocular matching" *Vision Research* **34** 1875–1881
- Sperling G, 1970 "Binocular vision: a physiological and neural theory" *American Journal of Psychology* **83** 461–534

