Change detection for objects on surfaces slanted in depth

Kerem Ozkan University of California, Irvine, CA, USA

Myron L. Braunstein University of California, Irvine, CA, USA

Change detection for objects associated with a surface extended in depth might be more difficult than for a frontal surface if it is easier to shift attention within a frontal surface. On the other hand, previous research has shown that ground surfaces have a special role in organizing the 3-D layout of objects shown against scene backgrounds. In the current study, we examined whether a frontal background or a ground surface background would result in superior change detection performance using a change detection flicker paradigm. In the first experiment, we considered whether background slant affects change detection performance. In Experiment 2, we examined the effect of height in the image on change detection performance. In Experiment 3, we examined change detection performance on slanted ceiling surfaces. The results of these experiments indicate that change detection is more efficient on near-ground planes than on surfaces at intermediate slants or ceiling surfaces. This suggests that any superiority of frontal plane backgrounds in a change detection task may be equivalent to the superiority of a near-ground plane in organizing a scene, with the lowest level of performance occurring for surfaces that are not frontal but further from a ground surface orientation.

Keywords: change detection, ground surfaces, slant, depth, scene perception

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Introduction

Understanding how our visual representations are updated as a result of changes in the environment is a central issue in vision and memory studies. Over the last decade, studies of change blindness have greatly contributed to our understanding of visual representations. In change blindness studies, participants often fail to detect changes introduced during a saccade (Henderson & Hollingworth, 1999, 2003), during a blink (O'Regan, Deubel, Clark, & Rensink, 2000), during a blank interval inserted between original and modified scenes (Hollingworth, Schrock, & Henderson, 2001; Rensink, O'Regan, & Clark, 1997; Simons, 1996), during a film cut (Levin & Simons, 1997; Simons, 1996), or during a "mudsplash" between original and altered scenes (O'Regan, Rensink, & Clark, 1999). Some researchers have argued that evidence from change blindness suggests that observers do not retain internal visual representations of the outside world (O'Regan & Noë, 2001). Others have suggested that visual representations are impoverished or sparse (Rensink et al., 1997; Simons & Levin, 1997) because the visual representations of objects decay very rapidly when we attend to different objects.

Another approach in the change blindness literature, however, claims that the failure to detect change does not imply that visual representations are sparse or absent because the ability to detect a change requires both a representation of the original scene and a successful comparison of that representation with the changed scene. An impoverished comparison mechanism could result in a failure to detect a change even if the visual representations are intact (Simons & Ambinder, 2005). Hollingworth and Henderson (2002) showed that observers can recognize objects on a memory test for which they failed to detect a change. Similarly, Mitroff, Simons, and Levin (2004) showed that observers can recognize objects both before and after the change when they have failed to detect a change.

Change detection for objects associated with a surface extended in depth might be more difficult than for a frontal surface if it is easier to shift attention within a frontal surface. There are several studies suggesting that attention can be depth blind (Ghirardelli & Folk, 1996; Iavecchia & Folk, 1994). Ghirardelli and Folk (1996) showed that when observers were cued to a location in depth and the target appeared at a different location in depth but at the same x, y location, there was no cost for switching attention in depth. Other studies, however, suggest that attention has spatial extent in depth. Downing and Pinker (1985) showed that reaction time was slower for targets that were at a different depth plane from a cued location. Atchley, Kramer, Andersen, and Theeuwes (1997) found that attention in 3-D space functions like a spotlight with an extent in depth as well as in the horizontal and the vertical dimensions. Their evidence supported a "depth aware" attentional spotlight instead of a "depth blind" spotlight as suggested by Ghirardelli and Folk (1996). Their conclusion agrees with earlier studies

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in which observers selectively attended to locations in depth when searching for a target at varying depth planes (He & Nakayama, 1995; Nakayama & Silverman, 1986), performing a focused attention task in the presence of surrounding distracters at varying depths (Andersen, 1990; Andersen & Kramer, 1993), or attending to objects defined with pre-masks at different depths (Hoffman & Mueller, 1994).

The present study examines the effect of background surfaces that vary in depth on change detection performance. Increasing experimental evidence shows that background surfaces, especially ground planes, have a special role in organizing the layout of objects in 3-D scenes. The role of the ground surface in determining the perceived distance of objects was a major component of Alhazen's (ca. 1038/1989) theory of depth perception. Gibson (1950) also emphasized the role of ground planes in the perception of the visual world. He proposed that the visual system uses ground planes as a foundation for organizing information in 3-D scenes. Recent studies of the importance of ground surfaces in the perception of the external world have examined the role of mediated contact relations for objects not in direct contact with the ground (Meng & Sedgwick, 2001, 2002) and the effect of surface continuity (Feria, Braunstein, & Andersen, 2003; Sinai, Ooi, & He, 1998). Other studies suggested that between the neural systems and the higher level perceptual functions there is an intermediate surface representation layer (Nakayama, He, & Shimojo, 1995), which integrates low level visual information with higher level functions. Visual search (He & Nakayama, 1992), motion perception (He & Nakayama, 1994a), visual texture segregation (He & Nakayama, 1994b), depth perception from binocular disparity (He & Ooi, 2000), and perception of subjective contours (Gillam & Nakayama, 2002) have been found to be affected by this intermediate level of surface representation.

Several studies have also demonstrated that there is a superiority of ground planes over ceiling planes in representing perceptual space. Bian, Braunstein, and Andersen (2005, 2006) showed that the ground surface plays a dominant role in determining perceived distance, relative to a ceiling surface and that this ground dominance effect was due to the differences in the projections of ground and ceiling surfaces, with visual field location having a minor effect. McCarley and He (2000, 2001) found a similar dominance in visual search with objects arranged to form an implicit ground or ceiling surface. They suggested that the visual system increases its efficiency by preferential encoding of ground surfaces. Bian and Andersen (2006) also reported that ground surfaces are superior to ceiling surfaces in a change detection task. Imura and Tomonaga (2007) reported that in both chimpanzees and humans, visual search is faster on ground-like surfaces in comparison to ceiling surfaces, suggesting that the ground dominance effect is not a cognitive strategy unique to humans but part of evolution in visual perception. Ozkan and Braunstein (2009) showed that ground surfaces are predominant over ceiling surfaces in binocular rivalry, with this predominance affecting both the dominance and suppression phases of binocular rivalry. Their results also showed that the superiority of ground planes is independent of image properties such as the increase or decrease in texture density from the lower half to the upper half of the images. This suggests that the ground dominance effect is a part of our perceptual organization that makes information processing more efficient on ground planes.

In the current study, we examined whether a frontal background or a ground surface background would result in superior change detection performance. If it is easier to shift attention among objects in the same depth plane, then we would expect change detection for objects associated with a frontal surface to be faster than change detection for objects associated with a surface extended in depth. However, if the visual system uses the ground surface as the foundation for organizing and representing the visual world, then we might expect superior change detection performance for objects associated with a ground surface. To examine this issue, we used a change detection paradigm in which observers compared a current representation of a scene to a stored representation of a previously presented scene, with variations in the slant of the background surface.

In 3 experiments, observers were presented with a set of scenes in a change detection flicker paradigm (Rensink et al., 1997). In the first experiment, we compared response times for a frontal plane background and backgrounds varying in slant. In the second experiment, we examined the effect of simulated distance on change detection response times. In the third experiment, we examined the same slant conditions as in the first experiment, using ceiling planes.

Experiment 1: Detection on slanted surfaces

In Experiment 1, we considered whether a frontal background or a ground surface would result in superior change detection performance. Previous studies that we have cited above showed that ground surfaces have a special role in organizing the 3-D layout of objects shown against scene backgrounds. These studies suggest that information processing is more efficient on ground planes in comparison to other surfaces. If that is the case, then we would expect faster response times in detecting changes on ground or near-ground planes. However, if it is easier to shift attention within frontal planes, then we might expect different results. Change detection for objects associated with a surface extended in depth might be more difficult than for a frontal surface. In order to

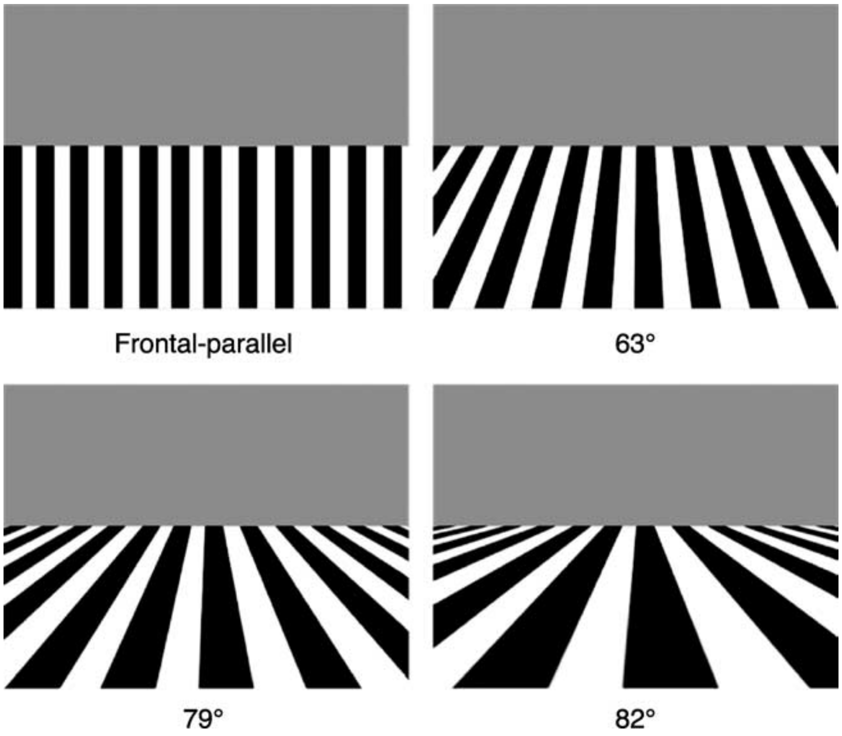

Figure 1. Four background planes used in Experiment 1.

compare these two ideas, in Experiment 1, we examined whether background slant affects change detection performance, using a version of the flicker paradigm developed by Rensink et al. (1997).

Methods

Observers

The observers were 10 undergraduate students at the University of California, Irvine. They were naive regarding the purpose of the experiment. All had visual acuity (corrected or uncorrected) of 20/40 or better measured with a Snellen eye chart. All observers received course credit for their participation. Informed consent was obtained from all observers prior to the experiment.

Stimuli

The stimuli were computer-generated background planes consisted of alternating black and white vertical stripes on which 24 cylinders were superimposed. There were four different backgrounds: frontal-parallel, or slanted 63°, 79°, or 82° (see Figure 1). The simulated distance to the nearest points on each of the three slanted surfaces was 808 cm. (The calculation of the scene dimensions is based on an eye height of 120 cm.) The height of the ground planes on the monitor was 27 cm subtending a visual angle of 8.6°. The background planes terminated at an artificial horizon aligned with the eye height at the vertical center of the monitor. The cylinders were superimposed on the background scenes randomly (see Figure 2). The projected height and width of the cylinders were 6 cm and 3 cm, subtending visual angles of 1.9° and 0.9°, respectively. The size and shape of the cylinder did not vary with its position on the background surface or with the slant of the background surface. The shape used in all conditions approximated an orthographic projection of a cylinder slanted 57°.

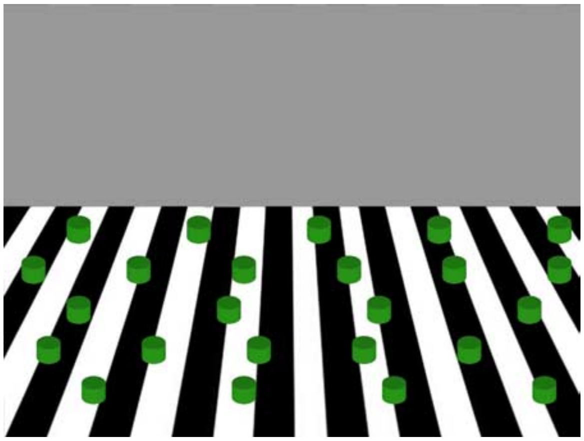

Figure 2. Twenty-four cylinders randomly positioned on a 63° background in Experiment 1.

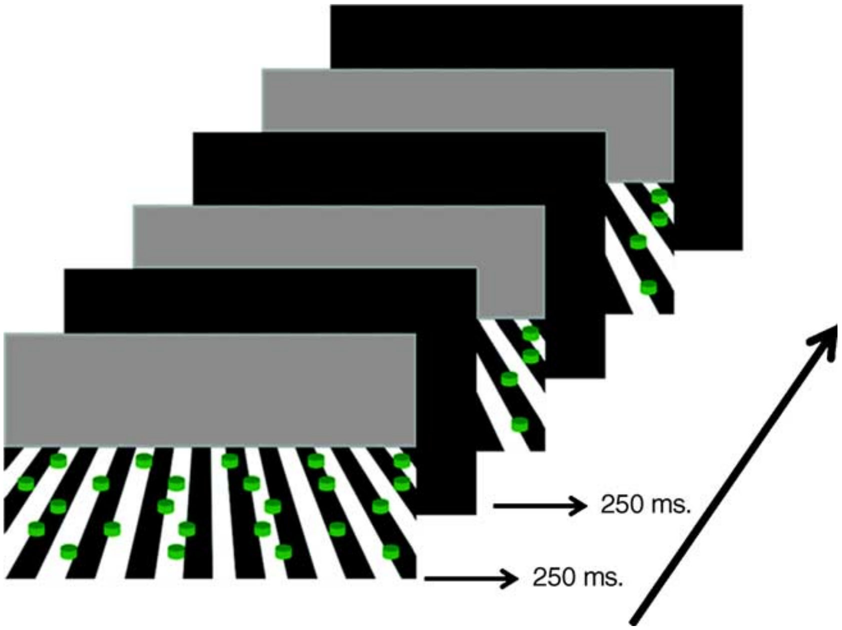

Figure 3. Procedure used in Experiment 1.

Design

There was one independent variable: the slant of the background plane (frontal-parallel, or slanted 63°, 79°, or 82°). The dependent variable was the response time in detecting the change. Thirteen change trials were produced by randomly selecting one of the twenty-four 3-D cylinders to be removed from the original scene. The same change trials were repeated on each of the four background planes for a total of 52 change trials. We also included 14 no-change trials to serve as catch trials for a total of 66 experimental trials. The experimental trials were preceded by a block of 20 practice trials. The order of the trials for each observer in each block was randomized.

Apparatus

The displays were presented on a 46-in. flat screen Sony HD LCD monitor with pixel resolution of 1920 × 1080. Observers viewed the displays monocularly through a viewing tube. The distance between the observer's eye and the screen was 183 cm. The center of the viewing tube was aligned with the center of the display. The distance from the observer's eye to the floor was 120 cm. That distance was used in calculations involving eye height. The observer's eye was aligned with the center of the viewing tube. The viewing tube maintained the appropriate viewing distance between the observer and the display. A rectangular mask at the end of the tube, 46 cm from the eyepiece, prevented the observer from seeing the borders of the screen. This method increases the perceived depth from 2-D images.

Procedure

The experiment was run in a darkened room. On each trial, the observer was presented with a set of scenes in a change detection flicker paradigm. The initial scene (A) and the modified scene (A′) were presented for 250 ms each in the sequence A, A′, A, A′, A, etc., with a black frame presented for 250 ms after each scene (see Figure 3). The modified scenes were produced by removing one of the cylinders from the original scene. The task of the observers was to observe the scenes carefully and identify whether or not there was a change. Observers were instructed to respond by pressing the left mouse button as soon as they detected the change, but to avoid overemphasis on speed relative to accuracy, they were not told that the response time was recorded. Twenty-two percent of the experimental trials contained no change. Observers were instructed to press the right mouse button if they did not find a disappearing object. On each trial, the sequence continued until the observer responded. After each trial, a blank white screen was presented for 8 s.

Results and discussion

Only trials in which the observer correctly identified a change were used in the analysis. We chose 10% as a false alarm rate criterion to remove observers from the analysis. All 10 observers had false alarm rates less than 10% and all were included in the analysis. Miss rates were very close to zero for all observers in all three experiments.

The mean response times for each of the background conditions are presented in Figure 4. As seen in the graph,

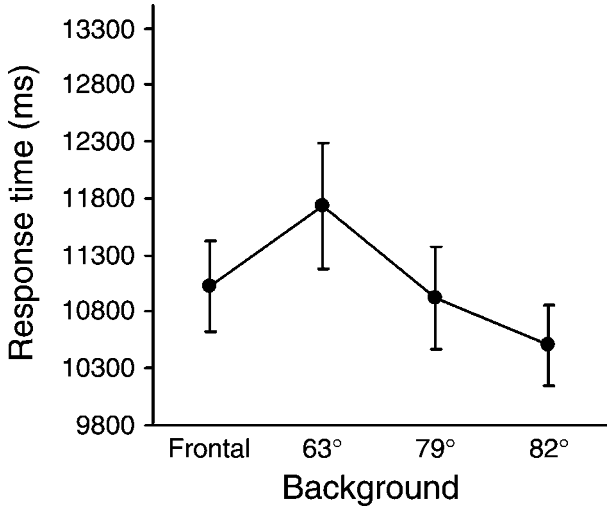

Figure 4. The mean response times for each of the background conditions. Error bars indicate ±1 standard error.

frontal-parallel and 82° slants showed similar response times. However, there was a significant jump in response times between frontal-parallel and the 63° slant. More time was required to detect the change with the 63° slant than with any of the other backgrounds. From 63° to 82°, there is a decrease in response times required to detect a change. A one-way repeated measures ANOVA revealed a significant main effect of surface slant on response times, $F(3, 27) = 3.24$, $p < 0.05$. A Tukey HSD post hoc test found a significant difference between frontal-parallel and 63° conditions ($p < 0.05$) and between 63° and 82° conditions. Response times for the 79° condition were not significantly different from those for the 63° or 82° condition, although the mean was closer to the mean for the 82° condition.

Our results suggest that any superiority of frontal plane backgrounds in a change detection task may be equivalent to the superiority of a near-ground plane in organizing a scene, with the lowest level of performance occurring for surfaces that are not frontal but further from a ground surface orientation. These results also indicate that change detection performance in a flicker paradigm does not depend solely on the 2-D object locations. If that were the case, we should not have observed the main effect of the slant. Instead we found that the type of background surface against which the objects are presented has a significant effect on change detection performance.

This finding is related to the ideas of Gibson (1950), who highlighted the role of ground contact in the perception of the visual world. Gibson proposed that background surfaces provide crucial information for perceiving the layout of objects. Other studies have also emphasized the importance of background planes in organizing 3-D scenes (Gottesman & Intraub, 2002; He & Nakayama, 1992, 1994a, 1994b, 1995; He & Ooi, 2000; Sanocki, 2003; Sanocki & Epstein, 1997), showing that ground surfaces serve a foundational role in organizing a description of the visual world and are encoded more efficiently than other environmental surfaces. Our results are consistent with this body of research: Change detection for slanted backgrounds improves as the slant approaches 90°.

Experiment 2: The effect of location on change detection

In Experiment 1, we found that surface slant has a significant effect on the response times required to detect a change, demonstrating that the simulated slant in depth of background planes influences detection performance. Among slanted planes, fewer exposures were required to detect a change on near-ground planes, although the simulated variation in depth was larger on these surfaces in comparison to planes with lower slants. As a result, we concluded that there is a superiority of near-ground planes in change detection tasks that is equivalent to the superiority of frontal plane backgrounds that do not vary in depth.

In the current experiment, we examined how the simulated distances of regions of the background against which objects were displayed affects change detection performance. If variations in the simulated distances among background planes affect change detection performance, then a similar effect should be found for variations in background depth within a plane. In order to test that, in the current experiment, objects were presented in one of two regions on each background plane, either within the top half of the background plane near the horizon (Figure 5a) or in the lower half of the plane (Figure 5b). We used the same backgrounds and flicker paradigm developed by Rensink et al. (1997) as in Experiment 1.

Methods

Observers

The observers were 7 undergraduate students at the University of California, Irvine. They were naive regarding the purpose of the experiment and none had participated in any other experiment in this series. All had visual acuity (corrected or uncorrected) of 20/40 or better measured with a Snellen eye chart. All observers received course credit for their participation. Informed consent was obtained from all users prior to the experiment.

Stimuli

The background surfaces, simulated slants (frontal, 63°, 79°, and 82°), simulated distances on the slanted surfaces,

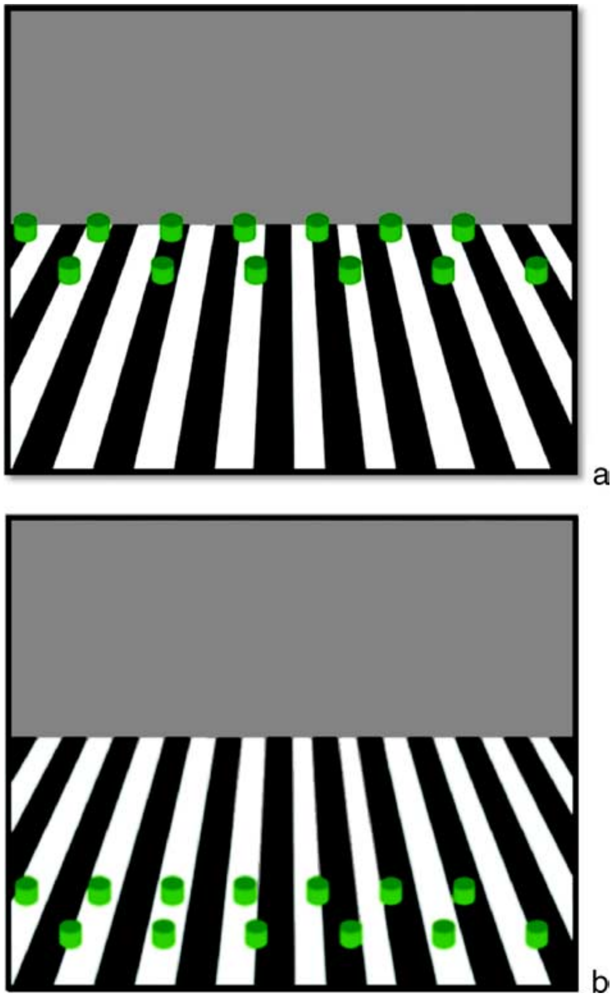

Figure 5. Examples of stimuli used in Experiment 2.

and the visual angles were the same as Experiment 1. As in Experiment 1, the horizon line of the planes was aligned with the eye height at the center of the monitor.

The computer-generated 3-D cylinders had the same visual properties as in Experiment 1. The projected height and width were 6 cm and 3 cm, subtending visual angles of 1.9° and 0.9°, respectively. However, different from Experiment 1, only 13 objects were superimposed on the background planes and these were presented either against the top half or bottom half of the background (see Figure 5).

Design

There were two independent variables: The slant of the background plane (frontal-parallel or slanted 63°, 79°, or 82°) and the location of the objects (top of the background or bottom of the background). The dependent variable was the response time, as in Experiment 1. In change trials, one of the thirteen 3-D cylinders was randomly selected and removed from the original scene. This was repeated for both top and bottom location conditions and on the four background planes, resulting in 64 trials (8 randomly selected objects × 2 height levels × 4 background slants). We also included 14 no-change trials to serve as catch trials, for a total of 66 experimental trials. The experimental trials were preceded by a block of 20 practice trials. The order of the trials for each observer in each block was randomized.

Apparatus

The apparatus was the same as in Experiment 1. The displays were presented on a 46-in. flat screen Sony HD LCD screen with pixel resolution of 1920 × 1080. Observers viewed the displays monocularly through a viewing tube.

Procedure

The procedure was the same as in Experiment 1. Observers were presented with a set of scenes in a change detection flicker paradigm. The initial scene (A) and the modified scene (A′) were presented for 250 ms each in the sequence of A, A′, A, A′, A, etc., with a black frame presented for 250 ms after each scene (see Figure 3). The modified scenes were produced by removing one of the cylinders from the original scene. The observer's task was to identify whether or not there was a change.

Results and discussion

As in the previous experiment, only trials in which the observer correctly identified a change were used in the analysis. We chose 10% as a false alarm rate criterion to remove observers. All observers showed false alarm rates less than 10% and all were included in the analysis.

The mean response times for each of the background conditions are presented in Figure 6. As seen in the graph, the mean response times for upper locations were greater than those for lower locations. A two-way ANOVA showed a main effect of height in the image, $F(1, 6) = 16.02$, $p < 0.01$. This indicates that change detection is significantly faster for objects that are at a lower height, suggesting that the simulated 3-D distances have an effect on change detection performance. Unlike Experiment 1, the main effect of background slant was not significant, $F(3, 18) = 1.03$, $p > 0.05$. That is mainly because of the increased performance, regardless of background slant, when objects were presented at lower heights on the screen. As seen in Figure 6, the response times for the higher object locations resemble the results from the previous experiment. The interaction between background slant and height was not significant, $F(3, 18) = 0.816$, $p > 0.05$.

Overall, our results show that distances implied by the background slant had a significant effect on the time required to detect a change. The identical results for two heights in the frontal-parallel condition demonstrate that the effect of height was not due merely to height in the

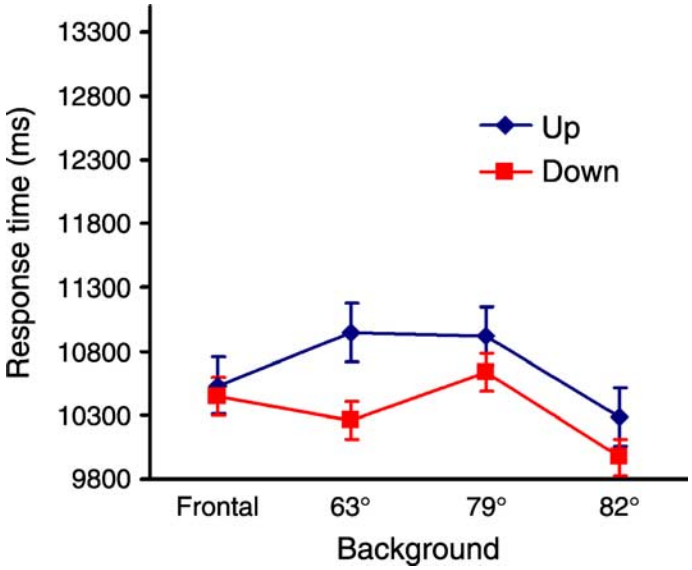

Figure 6. Mean response times for the four background planes and two object heights. Error bars indicate ±1 standard error.

image. However, at the 63° slant, height of the objects showed a significant effect ($p < 0.05$). This supports the interpretation that the decrement in performance at 63° in Experiment 1 and in the *top* condition in the present experiment was due to the spread of attention in depth, which was reduced in the *bottom* condition in the present experiment. The difference between the top and bottom conditions was not significant at any of the other slant levels. As the background slant approached 90°, the difference between the two height conditions decreased. This appears to be a reflection of the superiority of near-ground planes in organizing the scene, as found in Experiment 1.

Experiment 3: Ground and ceiling surfaces

In Experiment 1, we found superior change detection for near-ground planes in comparison to surfaces that are not frontal but further from a ground surface orientation. Experiment 2 showed that the simulated distances along the background plane have an effect on change detection performance. In both experiments, we observed that when background slants get closer to 90°, response time required to detect a change decreases. Previous studies have shown that there is a superiority of ground planes over ceiling planes in representing the 3-D layout of objects (Bian et al., 2005). Bian and Andersen (2006) also reported that ground surfaces are superior to ceiling surfaces in a change detection task. Our findings from Experiment 1 also point to a ground superiority effect on change detection. In the current experiment, we examined change detection performance on slanted ceiling surfaces with the same absolute slants as the ground surfaces in the first two experiments. We wanted to determine whether the superiority of near-ground surfaces was due to a ground surface advantage or to some other characteristic of the converging line patterns. The displays were identical to those in Experiment 1 except that the background planes were inverted and moved above the horizon. We compared our results with the findings from Experiment 1 using a between-subjects analysis.

Methods

Observers

The observers were 9 undergraduate students at the University of California, Irvine. They were naive regarding the purpose of the experiment and none had participated in any other experiment in this series. All had visual acuity (corrected or uncorrected) of 20/40 or better measured with a Snellen eye chart. All observers received course credit for their participation. Informed consent was obtained from all observers prior to the experiment.

Stimuli

The stimuli were similar to those in the previous experiments. They were computer-generated background planes consisting of alternating black and white vertical stripes. However, unlike the previous experiment, the slanted planes represented ceiling planes rather than ground planes. We produced the backgrounds in Experiment 3 by rotating the displays from Experiment 1 by 180°. The backgrounds were frontal-parallel, or slanted −63°, −79°, or −82° (see Figure 7).

The simulated distances to the nearest points on the slanted three surfaces were 914.3 cm, 920 cm, and 945.4 cm. (The calculation of the scene dimensions was based on an eye height of 120 cm.) The horizon of the planes was aligned with the eye height at the center of the monitor. As in Experiment 1, twenty-four 3-D cylinders were superimposed on the background scenes randomly (Figure 8). The projected height and width of the cylinders was the same as in the previous experiments.

Design

The design was the same as in Experiment 1. There was one independent variable: the slant of the background plane (frontal-parallel, or slanted 63°, 79°, or 82°). The dependent variable was the response time for detecting the change. The number of trials was the same as Experiment 1.

Apparatus

The apparatus was the same as in the previous experiments. The displays were presented on a 46-in. flat screen Sony HD LCD screen with pixel resolution of

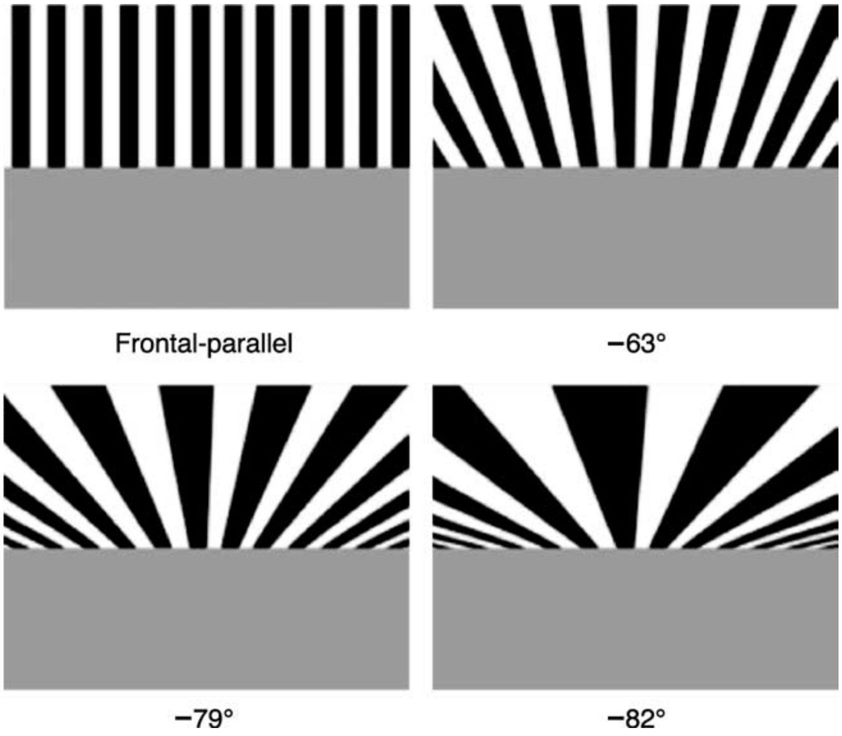

Figure 7. Four background planes used in Experiment 3.

1920 × 1080. Observers viewed the displays monocularly through a viewing tube.

Procedure

The procedure was the same as in the previous experiments.

Results and discussion

As in Experiment 1, we only included trials in the analysis that the observer correctly identified as including a change. We used 10% as a false alarm rate criterion. All of our 9 observers showed a false alarm rate less than 10%. Response times required to detect a change were used in the analysis. Unlike Experiment 1, a one-way repeated measures of ANOVA of the response times failed to show a significant main effect of surface slant, $F(3, 24) = 1.36$, $p > 0.05$.

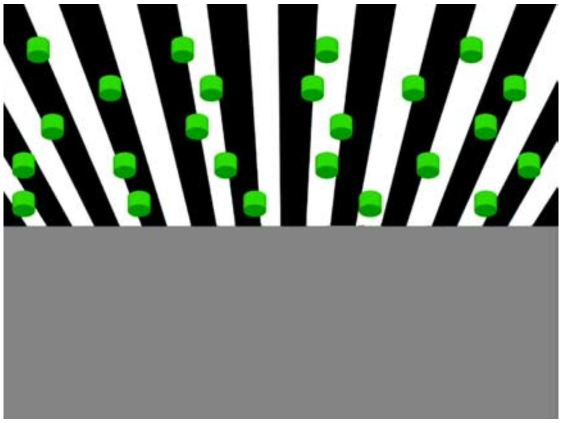

Figure 8. Example of display with a 63° background plane in Experiment 3.

Figure 9 shows a comparison of the results of the current experiment with those of Experiment 1. We can see that change detection on ceiling planes required more time than ground planes. This finding is in agreement with previous findings of ground dominance in other perceptual tasks (Bian & Andersen, 2006; Bian et al., 2005, 2006). The faster responses to the ground condition also could have been influenced by the cylinders being inverted in the ceiling condition and by chance differences in response times between the two groups of observers, but the larger difference in response times at the 82° is more consistent with the previous research indicating greater effectiveness of the ground plane in a variety of perceptual tasks. Greater spatial resolution for visual attention in the lower visual field (Intriligator & Cavanagh, 2001) may also have contributed to our finding of generally superior performance in the lower visual field.

A between-subjects ANOVA using the data from Experiments 1 and 3 revealed a significant main effect of ground vs. ceiling planes, $F(3, 48) = 3.03$, $p < 0.05$. As seen in Figure 9, this difference is mostly evident in the 82° slant condition. A multivariate analysis of variance (MANOVA) found a significant difference between

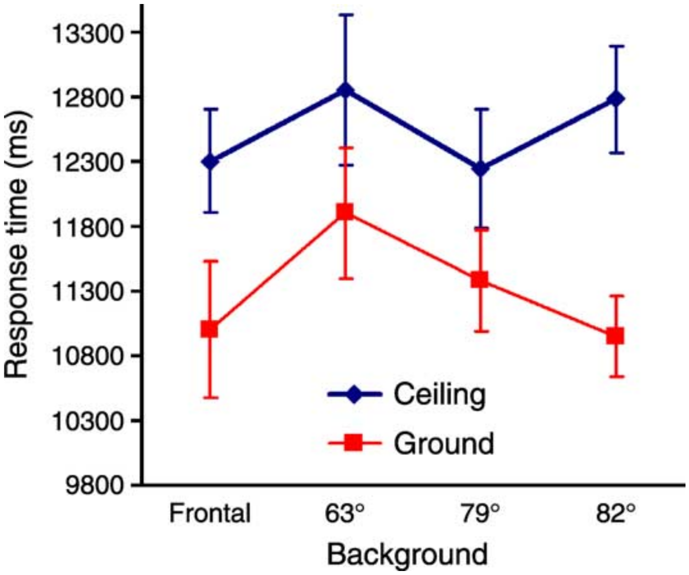

Figure 9. The mean response times for ground planes (Experiment 1) and ceiling planes (Experiment 3). Error bars indicate ±1 standard error.

ground and ceiling planes at the 82° slant, $F(1, 16) = 8.48$, $p < 0.01$, and for the frontal-parallel background, $F(1, 16) = 5.16$, $p < 0.05$.

In Experiment 1, our results showed that when background slant increases and approaches a ground plane orientation, the response time required to detect a change decreases. We concluded that the lowest level of performance occurs for surfaces that are not frontal but further from a ground surface orientation. We did not observe this effect with ceiling planes. On the contrary, one of the longest response times was observed when the objects were presented on −82° slant ceiling planes. The different pattern of results for ground and ceiling planes indicates that the effect of background slant cannot be attributed to variations in the mean spatial frequencies of the background planes, which varied with their absolute slant and were therefore identical for ground and ceiling backgrounds at the same absolute slant.

Overall, a comparison of the results of the current experiment with those of Experiment 1 demonstrates that changes for objects that are resting on ground planes are easier to detect than changes on ceiling surfaces. This agrees with the idea that ground surfaces have a special role in organizing information in 3-D scenes. Our results support the idea that the visual system encodes the 3-D layout of objects and the presence or absence of objects more efficiently on ground planes.

General discussion

We set out to determine whether a frontal background or a ground surface background would result in superior performance in change detection, using a flicker paradigm. Superiority of a frontal background, relative to slanted backgrounds, would be consistent with the attention literature showing a decrement in performance when attention must be spread over different depth planes (Andersen, 1990; He & Nakayama, 1995; Nakayama & Silverman, 1986). Superiority of a ground surface background would be consistent with the results of studies demonstrating the importance of background surfaces, especially ground planes, in organizing 3-D scenes (Gottesman & Intraub, 2002; He & Ooi, 2000; Sanocki, 2003; Sanocki & Epstein, 1997).

In Experiment 1, objects were presented against a frontal background or one of the three slanted backgrounds. We found superior performance for both the frontal and near-ground surface backgrounds, compared to intermediate slants. This suggests that there are two factors underlying the effect of a slanted background on change detection performance. The increase in response times from the frontal condition to the 63° condition is consistent with previous research indicating a cost for spreading attention in depth (Andersen, 1990; He & Nakayama, 1995; Nakayama & Silverman, 1986). The finding in Experiment 2 that this increase occurred only when the objects were placed in the upper portion of the display, and thus at a greater simulated distance in the slanted conditions, further supports the implication that this increase in response time is due to the need to spread attention in depth. The return to a higher level of performance at the highest slant, however, suggests that the organizing function of a ground surface provides an advantage equivalent to that of keeping the background at a single depth plane. The answer to our initial question, about which type of surface produces superior performance, is that both the frontal and near-ground surfaces do so.

To demonstrate that the performance decrement for intermediate surfaces was related to variations in simulated depth, we examined change detection in Experiment 2 at two simulated depths for each slanted surface. The cylinders were located either in the lower half of the background surface (in the projected image) or in the upper half. Performance was consistently superior with the cylinders in the lower half of the surface for each slanted surface, with the greatest difference found with the 63° slant. As the slant increased, the difference in results between the lower half and upper half was reduced, we believe because the organizing function of the ground plane compensates for any decrement caused by depth variations. For the frontal condition, in which both halves of the plane were at the same simulated distance, there was no difference between the response times for the lower and upper halves, indicating that the result for the slanted conditions was not due merely to height in the image.

To test our conclusion that superior performance occurred at the highest slant level because of the organizing function of ground surfaces, we replicated Experiment 1 using ceiling surfaces in Experiment 3. The superiority of ground over ceiling surfaces in organizing visual scenes has been demonstrated in a number of contexts (Bian et al., 2005, 2006; McCarley & He, 2000, 2001). We found generally faster responses with ground surfaces than with ceiling surfaces, and most importantly, we did not find the superior performance at the highest slant level with ceiling surfaces that we found with ground surfaces. Because the slanted ceiling surfaces presented exactly the same pattern of converging lines, except inverted, the superior performance with the most slanted ground surfaces, relative to background surfaces with intermediate slants, could not be due to some intrinsic characteristic of the texture pattern.

Our results also demonstrated that the difference between ground and ceiling planes reaches a peak in the 82° slant condition. This suggests that ground superiority in a change detection task becomes more evident as the background surfaces being compared approach actual ground and ceiling orientations. This is in agreement with a previous study (Bian et al., 2005) in which ground and ceiling planes were presented at intermediate levels of rotation. Their study showed that the reliance on optical contact information from a surface in layout judgments gradually diminishes as the orientation of the surface deviates from the typical orientation of a ground surface. Our study extends their findings, showing that the gradual reduction in the effectiveness of ground planes in determining perceived spatial layout is also found in a change detection task.

Another possible explanation for the faster response times to objects associated with a near-ground plane background is that response times are faster to objects having greater perceived sizes. Levinthal and Lleras (2007), using a change detection paradigm in which one of 12 colored spheres arranged on a simulated ground plane changed color between flashes, found faster responses to objects that were larger in perceived size. The projected size was held constant in each of our experiments, so that the perceived size would be expected to vary with simulated distance. A perceived size explanation would account for the improved performance from the 63° to the 82° slant conditions in Experiment 1 and with the target higher in the visual field in Experiment 2. A perceived size explanation is not consistent, however, with the slower response times for objects closer to the horizon, compared to objects lower in the visual field, in each of the slanted plane conditions in Experiment 2. (Only the difference at 63° was statistically significant.) This explanation also would not account for the superior performance in the frontal condition, relative to the 63° condition. A two-factor explanation would again be required, with the advantage of not having to shift attention in depth favoring the frontal position and perceived size favoring the more slanted positions.

It is possible that the cylinders were more likely to be perceived as attached to the ground plane in the 63° surface slant condition because the projected cylinder shape was consistent with a similar slant (57°). If stronger perceived attachment of the objects to the background increased the time required to perform the change detection task, longer response times in the 63° background condition in Experiment 1 could be related to the shape of the cylinders. This explanation, however, would not account for the finding that the longest response times did not occur at that surface slant level for objects in the lower half of the surface in Experiment 2.

Overall, our results suggest that any superiority of frontal plane backgrounds in a change detection task is equal to the superiority of a near-ground plane in organizing a scene. The lowest level of performance in change detection occurred for surfaces that were not frontal but were further from a ground surface orientation. In addition, our results show that the simulated distances of objects shown against slanted background planes affect the time required to detect a change. Detection time was generally longer for ceiling plane backgrounds and the superior performance found with ground planes at the highest slant levels did not occur for ceiling planes. Taken together, these results suggest that there is a decrement in change detection performance with backgrounds that vary in distance, but that this is overcome by the advantage of a ground plane in specifying the layout of a 3-D scene.

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Corresponding author: Myron L. Braunstein.
Email: myron.braunstein@uci.edu.
Address: 3151 Social Science Plaza, University of California, Irvine, CA 92697-5100, USA.

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