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Searching for bumps and ellipses on the ground and in the sky: No advantage for the ground plane

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ABSTRACT

A staple of modern theories of vision is that the visual system has evolved to perceive cues containing the most predictive information about the layout of the environment. This entails the prediction that – other things being equal – visual performance in a familiar setting should be superior to performance in an unfamiliar one. Visual performance should therefore be better on the familiar ground plane compared to an implied sky or wall plane. We tested this comparing visual search for stimuli presented in an implied ground plane with search on a 180° rotated search display so that the stimuli appeared in an implied "sky" plane, and with search in a random layout implying no depth. This was tested for stimuli with, or without, curvature discontinuities, that have previously been shown to be strong cues for shape analysis. Surprisingly, no advantage of the ground plane over the sky plane was observed, while a strong effect of layout regularity was seen. Similarly, in experiment 2 there was little effect of placing the stimuli on an implied wall plane compared to the ground or the sky. The results are not explained by assuming that curvature discontinuities are such strong cues that they overshadow any effect of depth-plane, since there was a strong effect of regular versus random layout, which should also have disappeared under this account. The results argue instead for a very strong effect of layout regularity, unrelated to environmental regularities in evolutionary history, since there was no ground-plane benefit.

1. Introduction

Modern accounts of visual perception typically assume that the perceivers' environment has played a causal role in shaping the way that same environment is perceived. Such evolutionary explanations assume that observers who were better able to extract useful information from the environment were more likely to pass their DNA on to future generations. Despite slight circularity of argumentation, this sort of framework has fared well in accounting for many aspects of visual perception (Gibson, 1950a, 1979; Gordon, 2004; Palmer, 1999). Johann Wolfgang Goethe realized this, stating: "the eye owes its existence to the light. Out of indifferent animal organs the light produces an organ to correspond to itself; and so the eye is formed by the light for the light so that the inner light may meet the outer" (quoted from Zajonc, 1993).

Many have, indeed, argued that this entails the prediction that we should be more adept at perceiving things that have been present in our environmental history. There is obviously no evolutionary pressure to perceive things that are not in the environment and are irrelevant to our survival. This sort of argumentation is central to the concept of ecological optics (Gibson, 1950a, 1979; see e.g. discussion in Gordon, 2004 and Champion & Warren, 2010). The crux of this view is that the visual system evolved to be especially sensitive to cues that are highly predictive about the layout of the environment. Rapid detection and processing of such cues provides the most efficient way of recovering the world structure from the visual input. Gibson famously stated that "visual space perception is reducible to the perception of visual surfaces [...] distance, depth and orientation [...] and the constancy of objects may all be derived from the properties of the arrays of surfaces" (Gibson, 1950b; p. 367; see also Marr, 1982). By Gibsons account, the visual system picks up information about the layout of the environment, such as it's 3-D structure. As Gibson's account makes clear, the detection and analysis of surfaces, in particular that of the ground plane, is a key concept in ecological optics (Nakayama, 1994). According to Gibson, "[...] there is literally no such thing as a perception of space without the perception of a continuous background surface" (Gibson, 1950a, p. 6). Theoretical analyses demonstrate that it is, indeed, computationally less complex to represent the visual environment as surfaces, rather than in Euclidean space (Attneave, 1954; Ooi, Wu, & He, 2001) since the raw input is highly redundant and, as Ooi et al. argue, a quasi-2D interpretation incorporating a fundamental ground plane could be of benefit for these reasons.

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Take for instance the patterns laid out in Fig. 1A–C. The regular spacing of the stimuli decreasing in size creates an impression of an array of ellipses with one "bump" laid out on a non-visible, implied surface, with the ones projecting the smallest retinal image perceived to be furthest away from the observer. The pictorial depth cues of texture gradient and relative size are vital to creating this impression. The pattern in Fig. 1D creates no such impression, where the different sized ellipses are placed in random locations.

In the following experiments we use stimuli referred to as "bumps" and "ellipses", the former of which contain 2nd order discontinuities in curvature (Kristjansson & Tse, 2001; Tse, 2002; Tse & Albert, 1998; see also Caplovitz & Tse, 2006). Kristjansson and Tse (2001) showed in visual search experiments that a wide variety of stimuli containing such curvature discontinuities pop out among stimuli containing only smooth changes in curvature (as the ellipses) and argued that these discontinuities are strong cues to depth. The search results were highly asymmetrical (cf. Treisman & Gormican, 1988) since stimuli lacking discontinuities were hard to find among those containing them. Our aims were to test the following:

(i) Whether when surfaces are implied with texture-gradients and relative size, search is more efficient than when such surfaces are not implied.
(ii) Whether predictions derived from ecological optics will hold - that searching the ground layout will turn out to be easier than when the stimuli appear as if in the sky, even if they all imply a surface (a *ground dominance effect*; Bian, Braunstein, & Andersen, 2005).
(iii) Whether search for stimuli appearing on a wall layout will differ from search on a ground or sky layout.
(iv) Whether any effects of layout will interact with search asymmetries between bumps and ellipse observed Kristjansson and Tse (2001).

Previous experiments have, indeed, reported performance advantages for the ground plane above the sky plane for a number of different tasks (see general discussion), sometimes referred to as a *ground dominance effect* (see e.g. Bian, Braunstein, & Andersen, 2005), leading to the obvious prediction that search should be easiest for the implied ground plane.

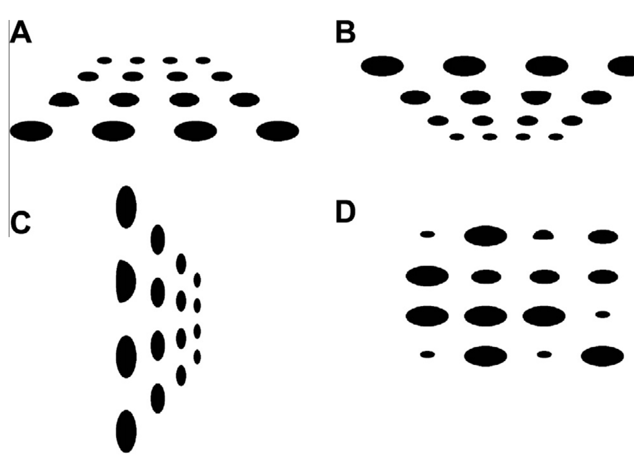

Fig. 1. Examples of the stimuli. All the displays show search for a "bump" among ellipses. Panels A, B and C (ground, sky and wall) show layout with systematically decreasing size giving a strong sense of depth as the stimuli appear to be laid out an a surface receding into the distance. The random layout in panel D does not lead to any such impression.

2. Experiment 1 – Hunting high and low

In the first experiment we contrasted whether the bumps and ellipses were laid out in a ground or sky plane (Fig. 1A–B) as well as contrasting regular versus irregular layout (Fig. 1D). To assess the difficulty of the search, set-size was varied (cf. Wolfe, 1998).

2.1. Methods

2.1.1. Observers

Eight naïve observers (5 male), aged 23–34 participated. Five had normal vision while 3 had normal vision when corrected with lenses. They received course credit for participation, which took about 1 h in total.

2.1.2. Stimuli

The stimuli appeared on a 15″ 75 Hz CRT display. Stimulus presentation was controlled with a G4 Macintosh computer. The experimental displays were programmed in C utilizing presentation functions from the VisionShell PowerPC function library for C. The search stimuli were always black (2.4 cd/m^2) and were presented on a white (112.4 cd/m^2) background. The search was either for a bump (containing contour curvature discontinuities where the second derivative of the rate of curvature is undefined, see Kristjansson & Tse, 2001 for more detailed explanation) among ellipses or vice versa (see Fig. 1). The items were either laid out as in Fig. 1A and B implying a surface (ground or sky), or randomly as in Fig. 1D (which shows the irregular upright case, but there was also an irregular inverted case). Three set sizes were tested (4, 10 and 16). The ellipses were 1.8° high and 3.6° wide (at 60 cm viewing distance) while the bumps consisted of two halves of different sized ellipses. Their height was 1.8° and their width was 3.6°. Note that the area of the bumps and ellipses was exactly equal. Both the main- and minor axes of the stimuli were scaled according to the slant (53°, see e.g. Saunders & Backus, 2006) of the implied surfaces. The implied ceiling and walls were made from the implied ground image by rotating them. The size of the other 3 bumps and ellipses (as they decreased in size) was 78%, 56% and 34% (in accordance with the slant) of the original as they decreased in size (see Fig. 1).

2.1.3. Procedure

As the search displays appeared on the screen observers were instructed to indicate by key press as quickly as possible whether an odd-one-out target was present or not (by pressing 4 or 6 on the numeric keypad, respectively), while maintaining a high degree of accuracy. A tone indicated whether the response was correct or incorrect and 1200–1800 ms following response the next display appeared. There were 8 different conditions (bumps among ellipses or vice versa in a sky or ground plane with random or systematic layout) run in 8 counterbalanced blocks of 200 trials. The display remained visible until a response key was pressed. To prevent jaggedness of the stimuli due to aliasing on the screen, the stimuli were convolved with a Gaussian envelope with a standard deviation of 1.5 pixels. Before the experiment started the task was explained to the observers and they were given 5–10 practice trials.

2.2. Results

Incorrect trials and trials with RTs more than 3 standard deviations (SD) from the mean RT for each observer were removed before statistical analyses. Mean error percentage was 6% (range from 3% to 10%, for detailed descriptions of error rates see Appendix A). A 5-way repeated-measures ANOVA on the response times tested the effects of presence versus absence, set-size, ground versus sky, shape (bumps versus ellipses) and regular versus irregular layout, see Fig. 2 for an overview of the results. Greenhouse-Geisser corrected degrees of freedom were used for significant deviations from sphericity.

The ANOVA revealed a large effect of set-size ($F(2,14) = 143.85$, $p < .001$), and a similar search asymmetry as seen in Kristjansson and Tse (2001) in that the search was faster for bumps among ellipses than vice versa ($F(1,7) = 51.28$, $p < .001$). The effect of layout was also highly significant ($F(1,7) = 22.01$, $p = .002$) which indicates that the implied depth from the texture gradient and relative size cues had a strong beneficial effect upon search efficiency. Most surprisingly, however, no hint of any differential effect of sky versus ground plane was found ($F(1,7) = 0.32$, $p = .591$). In addition, the main effect of target presence/absence was significant ($F(1,7) = 52.36$; $p < .001$) which is a typical finding in the visual search literature. None of the interactions involving the ground versus sky were significant (all p's > .08) indicating that the absence of any differential effect of sky versus ground applied to all conditions.

The effect of set-size interacted significantly with shape ($F(2,14) = 28.24$, $p < .001$), which is consistent with the search asymmetry observed in Kristjansson and Tse (2001) where bumps are easier to find among ellipses than vice versa, supporting the hypothesized importance of curvature discontinuities for visual analysis. Set-size also interacted with layout ($F(2,14) = 15.04$, $p < .001$), again showing the difference in difficulty depending on layout. The interaction of set-size and presence/absence was significant ($F(2,14) = 30.82$, $p < .001$) showing that search difficulty increased with set-size and that performance is better when the target is present. Shape and presence/absence interacted significantly ($F(1,7) = 28.13$, $p = .001$) indicating that the search was more efficient when the target was a bump and present than vice versa. The three-way interactions between set-size, shape and layout ($F(2,14) = 7.75$; $p = .005$) and between set-size, shape and presence/absence ($F(2,14) = 16.49$, $p = .001$) were also significant, again consistent with the search asymmetry between bumps and ellipses.

Even though our results do not support any advantage of visual search in the ground plane vs. the sky plane we cannot accept the null-hypothesis with confidence solely by conventional methods. Posterior probability testing can provide stronger support for it (Raftery, 1995 in Masson, 2011 and Wagenmakers, 2007). The total variance of the full model was 42,527,644 and the explained variance of it was 33,500,146 which means that 78.77% of the total variance is accounted for. In the model without the position factor (ground or sky plane) the explained variance was 33,459,705 or 78.68% of the total variance and shows that inclusion of the position factor has only minimal effects on the percentage of variance explained by the model. There were 8 observers and 4 independent observations (Masson, 2011) and 2 less free parameters in the alternative model compared with the full model. The posterior probability value for the null-hypothesis was 0.96, which is considered strong evidence for a null hypothesis (Raftery, 1995 in Masson, 2011 and Wagenmakers, 2007). For the alternative hypothesis the posterior probability value was 0.04, which is considered very weak since a value between 0.50 and 0.75 is weak according to Raftery (1995, in Masson, 2011 and Wagenmakers, 2007).

2.3. Discussion

A key concept in ecological optics is the importance of the ground plane. From this premise we can expect to observe an advantage for items laid out in the ground-plane (Bian, Braunstein, & Andersen, 2005; McCarley & He, 2000). But the benefit for the ground plane was entirely due to regular layout in the current study, since it was also observed for items arranged in an implied sky plane. It does not bode well for ecological accounts that no preference for the ground layout above the sky layout was observed. Our results do, on the other hand, bolster the conclusion that curvature discontinuities are important cues to shape, since the search asymmetry observed in Kristjansson and Tse (2001) is replicated.

One might argue that the absence of any ground versus sky effect reflects that the discontinuity cues are simply so powerful that they overshadow any other effects, such as a ground dominance effect. But this does not hold water since any layout effect should also have disappeared if the discontinuities are indeed so easy to find that the context they appear in does not matter. The cues should override any such effect, but the layout effect was quite strong, inconsistent with this interpretation.

3. Experiment 2 – Off the wall

In experiment 2 we tested whether curvature discontinuity cues are specific to 3D cueing in the horizontal plane (ground or sky), i.e. when the extremity is to the left or right rather than top or bottom – in other words whether there is a preference for items arranged in a horizontal plane, no matter whether they appear to be laid out in the sky or on the ground. Since the results of experiment 1 have already established a very clear layout effect, the layout was always regular, implying depth (as in Fig. 1A–C), in experiment 2. Ecological accounts should predict that ground plane performance should again be superior to the wall and sky planes.

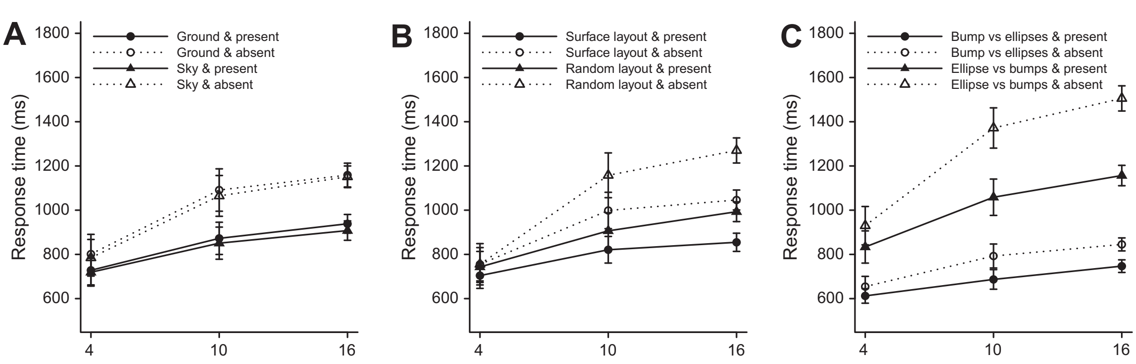

Fig. 2. Response times for the different conditions from experiment 1. Panel A shows the results as a function of layout (ground versus sky). Panel B shows the effect of layout (fixed versus random). Panel C shows the effect of shape.

3.1. Methods

3.1.1. Observers

Six naïve volunteers (3 female), aged 19–56 (M = 34.0 years, SD = 14.1 years) participated. All had normal vision (3 when corrected with lenses). Participation took about 40 min in total.

3.1.2. Stimuli

The same equipment and programming tools as in experiment 1 were used. The target stimulus was either a bump among ellipses or vice versa.

3.1.3. Procedure

Each observer participated in 12 blocks of 70 trials. The experimental display was presented as ground (4 blocks), sky (4 blocks), left (2 blocks) or right wall (2 blocks). In one half of the blocks in each condition the target was a bump among ellipses while in the other half this was reversed. Blocks were run in counterbalanced order across observers. Set size was either 7 or 14, selected randomly with equal probability for each trial. The experiment was run in a dimly lit room and the observers were comfortably seated about 60 cm from the screen. Otherwise, methods were similar to experiment 1.

3.2. Results

Fig. 3A shows performance in experiment 2 with separate lines for ground, wall and sky and target presence/absence. Fig. 3B shows the results as a function of whether the search was for a bump among ellipses or vice versa. The data for the left and right walls were combined since there was no difference between them ($F(1,5) = 0.62$, $p = .467$). Response times more than 3 standard deviations from each participants mean and incorrect answers were removed before statistical analyses. The average error rate was 4% (ranging from 2% to 6%; for detailed descriptions of error rates see Appendix B).

A four-way repeated measures ANOVA tested effects of set-size (7 and 14), position (sky, ground and wall), shape (bumps among ellipses and vice verse) and presence/absence upon RT. There were no deviations from sphericity (Mauchly's test: all p's > .15). The effect of set-size was significant ($F(1,5) = 29.59$, $p = .003$). When a target was present, the RTs were lower than when the target was absent ($F(1,5) = 16.59$, $p = .010$). The observers were significantly faster in finding bumps among ellipses than vice versa ($F(1,5) = 25.06$, $p = .004$) but most notably it did not matter whether the stimuli were presented on the ground, in the sky or on the wall ($F(2,10) = 1.30$ $p = .315$). The interaction of set-size and shape ($F(1,5) = 17.17$, $p = .009$) and of set-size and absence/presence were significant ($F(1,5) = 9.21$, $p = .029$) consistent with the effects of difficulty seen in experiment 1. Similarly, the interaction between presence/absence and shape was significant ($F(1,5) = 7.83$, $p = .038$). There were no significant interactions which included position (all p's > .15). In sum, experiment 2 does not show any advantage for the ground plane above the sky or wall plane, further confirming the results from experiment 1.

As in experiment 1 we used the posterior probability method to assess the null hypothesis of no differences between ground, sky and wall. The total variance of the model was 29,617,287 and the unexplained variance in the model with the position factor was 7,121,795 but for the alternative model it was 7,340,397. By removing the position factor the explained variance drops from 75.95% to 75.22% suggesting that the effect of this factor is almost nil. The posterior probability value supporting the null-hypothesis was 0.98 or very strong (Masson, 2011; Wagenmakers, 2007) but weak for the alternative hypothesis (0.02).

4. Experiment 3 – For one eye only

In previous experiments we found no advantage for the implied ground plane whether compared to the sky or wall planes. When viewing stimuli on a flat screen the observer can sense the implied depth due to the slants in the layout but there will be no binocular disparity, which may reduce or eliminate a ground plane advantage through cue-conflict (Allison & Howard, 2000; Ryan & Gillam, 1994). Experiment 3, where observers searched the same displays as in experiment 1 monocularly, was designed to test this. If cue conflict due to zero disparity could explain the absence of a ground plane benefit in experiment 1 and 2, such an advantage should be seen when binocular disparity cues are eliminated through monocular presentation.

4.1. Methods

4.1.1. Observers

Four naïve volunteers (3 female), aged 22–30 (M = 26.3 years, SD = 3.9 years) participated. All had normal vision and participation took about 30 min in total.

4.1.2. Stimuli

The same stimuli were used as in previous experiments but only on the implied ground and sky planes (see Fig. 1, panels A and B). The same equipment and programming tools as before were used.

4.1.3. Procedure

The procedure was similar to experiment 2, except that now we ran only blocks with implied ground and sky planes, 4 blocks of 70 trials in each condition. During participation the observers viewed the display with their dominant eye only, with the other eye covered by an eye patch.

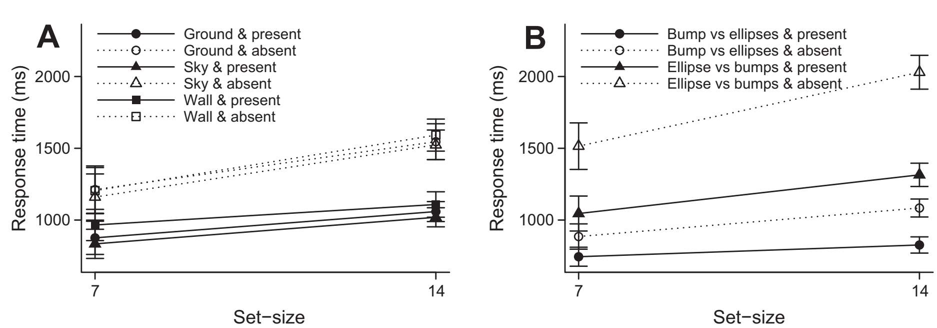

Fig. 3. Effect of position and shape in experiment 2. (Panel A) Mean response time as a function of whether the search items were laid out in a ground, wall or sky plane, as a function of set size. (Panel B) Mean response time as a function of whether observers searched for a bump among ellipses or vice versa.

4.2. Results

A four-way repeated measurement ANOVA tested main effects and interactions of implied plane (sky vs. ground), set-size (7 vs. 14), shape (bumps vs. ellipses) and presence/absence. The main effects of set-size, shape and presence/absence were all significant ($F(1,3) = 12.96$, $p = .037$; $F(1,3) = 24.3$, $p = .016$; $F(1,3) = 38.13$, $p = .008$, respectively) but most importantly, the effect of plane (ground vs. sky) was not significant ($F(1,3) = 0.74$, $p = .452$). No interactions involving plane were significant (all Fs < 2.98 and all ps > .18). As in previous experiments, the interactions of shape and presence/absence $F(1,3) = 20.46$, $p = .02$) and of shape and set-size $F(1,3) = 22.92$, $p = .017$) were significant. No other interactions were significant (all Fs < 1.6 and all ps > .29). The average error rate was 6% (ranging from 2% to 11%; see Appendix C).

This result shows that the lack of advantages for the implied ground plane with respect to the other implied planes can not be traced to cue conflict between monocular and binocular depth cues, further supporting our conclusions from experiments 1 and 2.

5. Experiment 4 – Control for local shape differences

A final possibility is that in previous experiments observers used the regularity of the surface-layout to assist them in finding the target and that this eliminates ground plane advantages over the sky plane. To answer this question we conducted a fourth experiment in which the stimuli in each row had the same size but size differed randomly by columns.

5.1. Methods

5.1.1. Observers

Four naïve volunteers and the last author of this paper (3 female), aged 19–42 ($M = 28.2$ years, SD = 10.2 years) participated. All had normal vision and participation took about 30 min.

5.1.2. Stimuli

The same stimuli, equipment and programming tools were used as in previous experiments.

5.1.3. Procedure

The procedure were similar as in experiment 1 with the exception that now there were only two set-sizes, 7 and 14 items and there were three types of layout of which two were the same as in experiment 2 (surface- and random layout) and a third one with stimuli of same size in each row that varied randomly by columns. There were 70 trials in each of the 8 conditions (run in counterbalanced order, 560 trials in total).

5.2. Results

The results were in good accordance with previous results and suggest that the regularity of the surface-layouts cannot explain the lack of the ground advantages with respect to sky since there was no difference between the two control conditions, but a large difference between the two control conditions and the regular layout conditions. A $2 \times 2 \times 3 \times 2 \times 2$ repeated-measures ANOVA with set-size, shape, layout, presence/absence and position (ground versus sky) as factors and RT as dependent variable revealed significant main effects of layout ($F(2,8) = 16.48$, $p = .001$), set-size ($F(1,4) = 129.4$, $p < .001$), of presence/absence ($F(1,4) = 76.16$, $p < .001$) and of shape ($F(1,4) = 182.8$, $p < .001$) but no main effect of position ($F(1,4) = 0.25$, $p = .643$). The following two-way interactions were significant: of layout and position ($F(2,8) = 4.75$, $p = .044$), of layout and set-size ($F(2,8) = 11.28$, $p = .005$), of layout and presence/absence ($F(2,8) = 6.16$, $p = .024$), of set-size and presence/absence ($F(1,4) = 65.61$, $p = .001$), of layout and shape ($F(2,8) = 6.81$, $p = .019$), of set-size and shape ($F(1,4) = 35.12$, $p = .004$), of presence/absence and shape ($F(1,4) = 82.78$, $p < .001$. The following three-way interactions were significant: of layout, position and set-size ($F(2,8) = 5.59$, $p = .03$), of layout, position and presence/absence ($F(2,8) = 35.12$, $p = .035$) and of set-size, presence/absence and shape ($F(1,4) = 9.84$, $p = .035$). The four-way interaction between layout, set-size, presence/absence and shape were significant ($F(2,8) = 6.61$, $p = .02$). No other interactions were significant (all p's > .19). It is noticeable that the main effect of position is far from being significant while the other main effects are highly significant. There is, however, some evidence of a ground advantage with respect to sky in the interactions but when the difference in the main effects are taken into account the contribution of position to the significance of the interaction including position can be considered minimal. In addition, any such difference is dwarfed by the complete lack of advantaged for the ground plane above the sky plane seen in other experiments. The average error rate was 2.2%, ranging from 2% to 3% and further description of errors can be found in Appendix D.

6. General discussion

While the current results show a strong search benefit for regular layout where depth is implied through texture gradient and relative-size cues, there is no indication of any benefit for the ground plane – whether viewed bi- or monocularly – as measured against an identical configuration that projected on a sky or wall plane. This is in opposition of clear predictions from theories of ecological optics of an advantage for the ground plane above the other two. This cannot be accounted for by saliency of contour curvature discontinuities (Kristjansson & Tse, 2001) since when the layout was irregular, search was slowed considerably even when the target was a bump containing curvature discontinuities among ellipses containing none. If curvature discontinuities were sufficient for efficient search, it should also have been easy under these conditions. But our results also lend further support to the proposal that curvature discontinuities can serve as important cues to 3D shape (Kristjansson & Tse, 2001; Tse & Albert, 1998).

The literature on visual search clearly shows how important surfaces can be for scene analysis. Aks and Enns (1996) found that visual search was strongly influenced by whether the search items appeared on an implied texture gradient (see Champion & Warren, 2010; for analogous results). As an example, a small target was harder to find among larger ones if the texture gradient implied that it was farther away than larger ones, compared to when they appeared on a frontoplanar surface implying no depth. In other words, implied depth has a very strong effect on search while the search items stay constant. He and Nakayama (1992) found that search was strongly influenced by binocular-disparity defined surfaces, and analogous findings have been reported for visual short-term memory (Kristjánsson, 2006; Xu & Nakayama, 2007). These findings are often interpreted in the context of ecological optics and the argument has been made that the presence of the ground plane in evolutionary history accounts for these results.

Other studies have shown evidence for what has been called a *ground dominance effect*. Kavšek and Granrud (2013) found that under monocular viewing 5–7 month old infants reach preferentially to items that are specified as being closer by the ground surface versus items specified as nearer by a ceiling surface. Bian, Braunstein, and Andersen (2005) previously reported an analogous effect for adult observers. Bian and Andersen (2010) then found that changes between two views of the same visual scene are easier to detect on a ground than a sky plane. They reached the conclusion that the ground surface plays a unique role in organizing visual scenes. While our results do of course not need to be taken as strong evidence *against* a ground plane benefit (or the ground dominance effect), they must be considered problematic for strong versions of ecological accounts where environmental familiarity is thought to play a key role in perception. The results may contain hints about exceptions to such rules. On a related note, our results show how texture gradient works equally well, no matter what sort of depth is implied. This also violates a rather obvious prediction of ecological optics, since the textures would, in evolutionary history, typically be on the ground.

One protest that could be raised is that better cues than "free floating" implied surfaces are needed for the ground dominance effect. It might very well be that with further cues to surface layout such as a horizon, a grid under the stimuli decreasing in density or 3D presentation using binocular disparity, a ground dominance effect would emerge. But this somewhat misses the point. The *implied* surface should suffice. Gibson (1950a) was clear on this – it should be possible to define a surface without any contour solely through the perspective of texture. Supporting this, Gibson (1950b) found strong effects of texture gradient for stimuli that did not contain any other cues to depth. Note that McCarley and He (2000; see also Morita & Kumada, 2003) reported a ground dominance effect for visual search for stimuli defined by binocular disparity where the ground plane was only implied by layout of the items relevant to the search (similar to He & Nakayama, 1992).

An interesting next step would be to track observers' eye movements during search. Even though we did not find any difference in search efficiency with respect to sky, ground and wall, the eye movement patterns during the search might differ. Interestingly, when observers look for an abstract stimulus in a natural environment they apparently do not preferably search the ground over the sky (Neider & Zelinsky, 2006). Furthermore, the saliency of bumps as target among ellipses is much higher than vice versa which also might alter the search pattern (see e.g. Henderson et al., 2007). In visual search, knowledge of the target guides eye movements such that the first saccade is usually made towards the target and this is more pronounced if the target is in the same position as on the previous trial and holds even when the target is absent (Eckstein, 2011; Eckstein, Drescher, & Shimozaki, 2006). It would be interesting to know whether regular and irregular stimulus displays affect this pattern and whether it differs for the sky, ground and wall planes.

7. Conclusions

Even though ecological accounts of perception make the prediction that search should be easier on an implied ground plane, than a sky plane or even as if on a wall, we failed to find any ground dominance effects in our experiments. Our results therefore argue against strong versions of such accounts, clearly showing that the ground dominance effect is not ubiquitous.

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Appendix A.

See Table A1.

Appendix B.

See Table B1.

Appendix C.

See Table C1.

Appendix D.

See Table D1.

Table A1
Overview of error ratios in experiment 1 with respect to experimental conditions.

Implied plane	Set size	Shape[a]	Pres/abs	Layout	Error ratio
Sky plane	4	be	Absent	Fixed	0.74
Ground plane	4	be	Absent	Fixed	2.14
Sky plane	10	be	Absent	Fixed	0.82
Ground plane	10	be	Absent	Fixed	0.37
Sky plane	16	be	Absent	Fixed	1.40
Ground plane	16	be	Absent	Fixed	0.39
Sky plane	4	eb	Absent	Fixed	1.45
Ground plane	4	eb	Absent	Fixed	1.84
Sky plane	10	eb	Absent	Fixed	3.10
Ground plane	10	eb	Absent	Fixed	1.06
Sky plane	16	eb	Absent	Fixed	0.39
Ground plane	16	eb	Absent	Fixed	2.40
Sky plane	4	be	Present	Fixed	0.74
Ground plane	4	be	Present	Fixed	4.90
Sky plane	10	be	Present	Fixed	3.04
Ground plane	10	be	Present	Fixed	3.68
Sky plane	16	be	Present	Fixed	6.39
Ground plane	16	be	Present	Fixed	6.18
Sky plane	4	eb	Present	Fixed	5.49
Ground plane	4	eb	Present	Fixed	2.55
Sky plane	10	eb	Present	Fixed	12.87
Ground plane	10	eb	Present	Fixed	9.51
Sky plane	16	eb	Present	Fixed	19.76
Ground plane	16	eb	Present	Fixed	20.23
Sky plane	4	be	Absent	Rand	2.79
Ground plane	4	be	Absent	Rand	2.73
Sky plane	10	be	Absent	Rand	1.72
Ground plane	10	be	Absent	Rand	1.18
Sky plane	16	be	Absent	Rand	3.59
Ground plane	16	be	Absent	Rand	0.72
Sky plane	4	eb	Absent	Rand	1.10
Ground plane	4	eb	Absent	Rand	2.75
Sky plane	10	eb	Absent	Rand	1.12
Ground plane	10	eb	Absent	Rand	1.53
Sky plane	16	eb	Absent	Rand	0.74
Ground plane	16	eb	Absent	Rand	2.13
Sky plane	4	be	Present	Rand	4.30
Ground plane	4	be	Present	Rand	3.77
Sky plane	10	be	Present	Rand	4.53
Ground plane	10	be	Present	Rand	3.70
Sky plane	16	be	Present	Rand	5.59
Ground plane	16	be	Present	Rand	10.51
Sky plane	4	eb	Present	Rand	9.33
Ground plane	4	eb	Present	Rand	6.32
Sky plane	10	eb	Present	Rand	16.94
Ground plane	10	eb	Present	Rand	15.66
Sky plane	16	eb	Present	Rand	29.67
Ground plane	16	eb	Present	Rand	25.75

[a] be = bump among ellipses; eb = ellipse among bumps.

Table B1
Overview of error ratios in experiment 2 with respect to experimental conditions.

Implied plane	Set size	Shape[a]	Pres/abs	Error ratio
Sky plane	7	be	Absent	0.47
Ground plane	7	be	Absent	0.96
Wall plane	7	be	Absent	2.27
Sky plane	14	be	Absent	0.97
Ground plane	14	be	Absent	0.52
Wall plane	14	be	Absent	1.03
Sky plane	7	eb	Absent	0.97
Ground plane	7	eb	Absent	1.47
Wall plane	7	eb	Absent	3.40
Sky plane	14	eb	Absent	0.48
Ground plane	14	eb	Absent	1.99
Wall plane	14	eb	Absent	0.99
Sky plane	7	be	Present	0.90
Ground plane	7	be	Present	1.96
Wall plane	7	be	Present	3.38
Sky plane	14	be	Present	3.48
Ground plane	14	be	Present	2.54
Wall plane	14	be	Present	3.65
Sky plane	7	eb	Present	6.86
Ground plane	7	eb	Present	2.83
Wall plane	7	eb	Present	6.40
Sky plane	14	eb	Present	9.09
Ground plane	14	eb	Present	8.97
Wall plane	14	eb	Present	13.54

[a] be = bump among ellipses; eb = ellipse among bumps.

Table C1
Overview of error ratios in experiment 3 with respect to experimental conditions.

Implied plane	Set size	Shape[a]	Pres/abs	Error ratio
Sky plane	7	be	Absent	4.79
Ground plane	7	be	Absent	0.71
Sky plane	14	be	Absent	2.46
Ground plane	14	be	Absent	0.84
Sky plane	7	eb	Absent	4.38
Ground plane	7	eb	Absent	4.29
Sky plane	14	eb	Absent	4.05
Ground plane	14	eb	Absent	1.40
Sky plane	7	be	Present	2.92
Ground plane	7	be	Present	0.77
Sky plane	14	be	Present	7.10
Ground plane	14	be	Present	10.00
Sky plane	7	eb	Present	10.45
Ground plane	7	eb	Present	4.70
Sky plane	14	eb	Present	20.71
Ground plane	14	eb	Present	9.38

[a] be = bump among ellipses; eb = ellipse among bumps.

Table D1
Overview of error ratios in experiment 4 with respect to experimental conditions.

Implied plane	Set size	Shape[a]	Pres/abs	Error ratio
Sky plane	7	be	Absent	0.74
Ground plane	7	be	Absent	0.73
Sky plane	14	be	Absent	0.00
Ground plane	14	be	Absent	0.40
Sky plane	7	eb	Absent	0.00
Ground plane	7	eb	Absent	0.00
Sky plane	14	eb	Absent	0.00
Ground plane	14	eb	Absent	1.55
Sky plane	7	be	Present	0.38
Ground plane	7	be	Present	0.70
Sky plane	14	be	Present	0.37
Ground plane	14	be	Present	1.67
Sky plane	7	eb	Present	5.26
Ground plane	7	eb	Present	1.11
Sky plane	14	eb	Present	12.85
Ground plane	14	eb	Present	9.64

[a] be = bump among ellipses; eb = ellipse among bumps.

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