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The relative capabilities of the upper and lower visual hemifields

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ABSTRACT

Visual performance is better in the lower visual hemifield than in the upper field for many classes of stimuli. The origin of this difference is unclear. One theory associates it with finer-grained attention in the lower field, an idea consistent with a change in relative efficacy with task difficulty. The first experiment in this study confirmed a lower hemifield advantage for discriminating a range of stimuli, including those that differ in contrast, hue, and motion. An identical paradigm revealed an upper field advantage when stimuli differed in their apparent distances from the observer. Presentations of stimuli in the upper or lower hemifield were interlaced to reduce the likelihood of possible artifacts or biases. A second experiment varied the difficulty of these discriminations, showing that difficulty does not determine field preference. Thus, an attentional mechanism is not a likely explanation for these preferences.

1. INTRODUCTION

Visual capabilities are not uniform throughout the visual field. Acuity is highest in the central field, and worsens toward the periphery. There are also clear nasal-temporal differences (Curcio and Allen, 1990). A difference that has not been explored as thoroughly is that between the upper and lower visual hemifields.

As a general rule, subjects perform somewhat better when stimuli are in the lower visual hemifield than in the upper visual field. This may not seem surprising, since ganglion cell densities are somewhat higher in the superior retina (Curcio and Allen, 1990; Croner and Kaplan, 1995). However, there are differences that do not follow directly from simple retinal cell density. For example, Rubin, Nakayama, and Shapley (1996; see also Shapley, Rubin, and Ringach, 2004) found that the illusion of subjective contours is more pronounced in the lower visual field than the upper. This indicates a contribution from areas beyond the retina.

Other indications that higher-level processing areas enhance performance in the lower visual field come from various experiments showing lower field preferences; these are extensively reviewed by Danckert and Goodale (2003). Some of these preferences seem more pronounced when the “difficulty” of the task or complexity of the stimuli is increased, implying that attentional demands may account for the differences. A common interpretation is that the “spotlight of attention” is more finely focused in the lower visual hemifield, so performance is better in the lower field when fine discriminations must be made (He, Cavanaugh, and Intriligator, 1996).

While performance for stimuli in the lower visual hemifield seems generally better than for those in the upper, a few experiments have demonstrated conditions in which the reverse is the case (see Previc, 1990; Danckert and Goodale, 2003). Some of these exceptions involve serial searches in which the distracters are present in both the upper and lower fields; since we tend to scan left-to-right and top-to-bottom (as we read), the upper field preference could be attributable to the search strategy. There also have been studies in which no preference was shown for the upper or lower hemifields (e.g.: McColgin, 1960).

In previous work on a visual illusion called “blanking,” it was noticed that thresholds for a small disk rendered less visible by surrounding squares were higher in the upper visual hemifield than in the lower (McAnany and Levine, 2004). Moreover, this discrepancy was greater when thresholds were high than in control conditions when thresholds were low. This could be due to a greater blanking effect in the upper field, but alternatively might be due to improved relative performance in the lower field as a result of the greater complexity and difficulty of the task.

The present studies were designed to answer several questions about the different visual capabilities within the upper and lower hemifields. In order to test for the effects of difficulty, it was necessary to find stimuli such that the upper field would show better performance than the lower in an experimental paradigm comparable to those in which other stimuli facilitated lower field performance. Experiment 1 was designed to establish stimuli with robust preferences for each of the fields.

Experiment 2 was a series of tests of the effects of difficulty upon each type of stimuli. Would more difficult tasks enhance performance disproportionately in the lower visual hemifield, and thus reverse the upper field preference for those stimuli favored in the upper field while increasing the performance gap for those favored in the lower field? Or might difficulty simply increase the discrepancy, regardless of the preference? Or is task difficulty irrelevant for the relative performance of the upper and lower visual hemifields in a specific task?

2. METHODS

2.1 Subjects

The same subjects who served in a previous publication (McAnany and Levine, 2005) served in this study. Subjects 1, 2, and 3, respectively, were the authors (males, 25 and 61 years old) and a naïve observer (female, 25 years old). All had normal or corrected-to-normal acuity, normal stereopsis, and no known color anomalies. The experimental protocol and process of consent were approved by a UIC Institutional Review Board.

2.2 Apparatus and calibrations

The apparatus and calibrations have previously been described in detail (McAnany and Levine, 2005). Briefly, the subject sat with his or her chin in a chin rest, facing an EIZO 19" FlexScan FX·D7 monitor in a dark room. A first-surface mirror stereoscope provided fusion of separate images on the left and right halves of the screen to provide a three-dimensional display. Relative positions of points on the two images were corrected for each subject's horopter, which was first ascertained by the Nonius method.

Display luminance was calibrated with a Minolta LS-110 luminance meter. The RGB units (the binary numbers controlling the guns) were converted to luminance by a quadratic function. In all experiments, the background was neutral gray with a luminance of 23.6 Cd/m^2 (red = 5.0, green = 16.3, blue = 2.3 Cd/m^2).

2.3 Time-course and display

Each block of trials began with a 30 s period during which the subject fixated at the center of a uniform field of the background gray (in each eye). The fixation pattern consisted of a black dot and two concentric circles, with small disparities such that, when properly fused, one circle appeared in slightly in front of the gray field and one appeared slightly behind it. This pattern was available to the subject to ensure proper fixation before and during each stimulus presentation trial. It vanished during the response period, and reappeared to signal readiness for the next trial.

The subject initiated each trial *ad libitum* by pressing an arrow key on a computer keyboard. The stimulus was presented 500 ms after this initiation signal. Static stimuli were presented for 280 ms, after which they were replaced by a uniform gray screen until the subject indicated a response choice with the numeric keypad. Dynamic stimuli consisted of two consecutive frames of equal duration; each frame could be 56 or 112 ms.

The stimulus pattern consisted of an array of disks placed randomly on a field of the background gray; the field was 18^{o} wide and 13^{o} high. The number and diameters of disks could be set as a parameter. In most cases, there were 125 disks with diameters of 29 min. Thus, the disks typically covered about 13% of the stimulus area. An example is shown in Figure 1.

Figure 1 *near here*

A block of trials typically consisted of 144 to 250 trials, a number of trials the subjects found comfortable in a single sequence. Within each trial, the stimulus pattern appeared randomly either above or below fixation. The target cluster of disks (3.5^{o} in diameter) could appear in one of three regions within the field: directly centered over or under fixation, or centered 4.4^{o} to the left or right of that position. It was always 12^{o} above or below fixation. The subject’s task was to indicate whether the target was left, center, or right (3 AFC).

There were typically seven disks clustered within the target region; these could differ from disks in the balance of the field in luminance, color, motion in depth, relative disparity, or lateral motion. When luminance was under investigation, disks in the target region had a luminance of

22.9 Cd/m^2 while all other disks had a luminance of 24.3 Cd/m^2 (the background was the standard 23.6 Cd/m^2).

Three different tests examining hue sensitivity were devised. In the first hue test, all disks were as nearly equiluminant with the background as could be devised. Equiluminant colors were determined for each subject by presenting a high-contrast (two color) picture in which one of the colors was the background gray and the other was similar but for a small increment in the level of one or two of the guns. The subject's task was to adjust the level of the third color gun until the picture appeared neither as a positive nor a negative. Subjects felt more confident making this determination rather than the minimally distinct border method. A different determination was made for each of several departures of one gun from its value in the neutral gray.

Since equiluminant patterns are difficult to discern, especially with only minimally saturated hues, a blue pedestal was added to each disk for the second hue test (an additional 3.4 Cd/m^2). This rendered all the disks more easily visible against the gray background, although disks in the target region varied in hue from all other disks. Hue was varied along the red-green axis, so the discrimination was between slightly pinkish and slightly violet disks. Color is reported by the luminance of the red in the mixtures. In the third hue test, a small random amount of gray (up to 2.6 Cd/m^2) was added to each disk in the display (which were otherwise equiluminant, on the blue pedestal). This produced a noticeable variation in luminance from disk to disk, so luminance could not serve to distinguish the target disks.

Motion in depth was tested with two frame presentations. All disks were solid black (0.3 Cd/m^2). In the first frame, all disks were in the same apparent plane; in the second frame, each disk moved horizontally by a small distance. Disks in the target region moved in opposite directions in the two eyes (24.5 min in each eye; 49.0 min total disparity), giving an appearance of moving either toward or away from the observer. The direction could be randomly chosen for each trial, or always set for crossed disparity (toward the observer). Disks not in the target region moved laterally in the same direction in each eye so the subject could not simply determine where there had been motion; it had to be movement out of plane.

To test whether the motion in depth was the key element of the depth effect, another series was attempted in which a single longer frame (280 ms) was presented. The distracter disks were all in the same plane as the fixation; the target disks were presented with 49.0 min total crossed disparity so that they appeared closer than the distracter disks (motion toward the observer had seemed more robust; see also Breitmeyer *et al*., 1975; Manning, Finlay, Neill, and Frost, 1987).

A final parameter tested was simple lateral motion. The test was similar to the test for motion in depth: solid black disks appeared in the first frame; the disks within the target region shifted either left or right in the second frame. The typical shift was 24.5 min. In this test, the frame durations were set to 112 ms each. Leftward and rightward shifts were randomly interlaced.

In some earlier experiments, a total number of disks was selected, and those disks were distributed randomly across the field. A fresh random distribution was generated for each trial to avoid any bias that might be introduced by local inhomogeneities. Those disks that fell within the chosen target region were then adjusted according to what was to distinguish target from other disks. This introduced variability, because the number of disks comprising the target depended upon the local density; therefore, a rule was instituted that fixed the number of disks to be placed at random within the target region (typically seven). The same number was placed in each of the distracter regions, and the remainder of the stimulus pattern was filled at the same density. Thus, local density of the pattern could not serve as a cue to the location of the target.

In order that the subject not be able to gain any advantage by fixating above or below the fixation pattern, the appearance of the stimulus pattern was randomly chosen to be above or below fixation. This, of course, meant that a somewhat unequal number of each could occur in each block of trials. To avoid this, the probability of presentation in a given field was set according to the relative number of presentations of it remaining if the numbers were to be equal. That is

$$p_{UVF} = \left({N}/{2} - n_{UVF} \right) \Big/ \left(N - (n_{UVF} + n_{LVF}) \right)$$

where p_{UVF} is the probability of an upper visual field presentation, N is the number of trials in the block, and n_{UVF}, n_{LVF} are the number of times the stimulus was already presented in the upper and lower visual fields, respectively. This tended to maintain a relatively balanced rate of presentations while still being sufficiently random that the subject could not discern an *a priori* probability on any particular trial. As the block neared its end, p_{UVF} approached either zero or one, so the final counts of each were equal. The subject was unaware of when the final few trials were in progress.

Similarly, the probability of each target position (left, middle, or right) was chosen at random on each trial. In the earlier experiments, it became apparent that variability was introduced because the three positions were not exactly equally distributed, and subjects could have a tendency toward a particular response when uncertain. This was corrected by an algorithm comparable to that for determining upper and lower field presentations.

The initial searches for stimulus attributes that were better detected in the upper or lower hemifields used blocks of up to 200 trials of the same stimuli (randomized for position and upper or lower field). Once stimulus attributes were identified that favored each hemifield, an interlaced trial paradigm was established to insure that the subjects were not subconsciously favoring the expected hemifield. In this paradigm, a block usually comprised 72 trials of one class of stimulus, with target positions and visual hemifields determined by the random-but-finally-equal algorithm described above, interlaced with 72 trials of the other class of stimulus. Ultimately, a block of 144 trials contained the target 12 times in each of the three positions in both upper and lower field for each of the two stimulus types.

No feedback was given, either about the correctness of response or the number of trials remaining in a block. Subjects were offered a few minutes to stretch between blocks (in the darkened room), and no more than eight blocks were run in a given session.

2.4 Statistical analysis

Data consisted of correct and incorrect responses to 3AFC decisions. Responses were collapsed across the three possible positions (left, middle, and right), to yield numbers correct (and numbers incorrect) for the upper and lower visual fields. These were analyzed by the Chi Squared (χ^2) statistic with 1 *df* (2 X 2).

3. Experiment 1

3.1 Introduction to experiment 1

The first task was to determine what stimulus types (if any) might be favored by the lower visual hemifield, and what (if any) might be favored by the upper visual field. Previous work had shown a lower field preference for light disks blanked by black squares. Other studies had also shown a lower field preference, although stimuli were typically not presented as far peripherally as in the blanking experiments (Danckert and Goodale, 2001, 2003; Previc, 1990).

3.2 Luminance

Subject 1 was tested extensively for his ability to discriminate disks slightly lighter than the background gray from disks slightly darker than the background. Although it appeared he did somewhat better in the lower visual field on most blocks, it was only after repeating the experiment four times (800 trials on four days) that the difference proved significant ($\chi^2 = 5.1$, $p<0.025$). Subject 2 had a somewhat larger difference overall, and that difference was also significant ($\chi^2 = 5.7$, $p < 0.02$). These data included four separate blocks, two of which were interlaced with stimuli for which the upper field showed better performance. However, in one of these blocks (not one of the interlaced blocks), performance in the upper field seemed better. Subject 3 also seemed to perform better for stimuli in the lower field, but the difference between fields was not significant. Thus, the small advantage enjoyed in the lower visual field did not seem robust enough to pursue (see Figure 2, leftmost pairs of bars in each group), although it was significant when pooling the data from the three subjects ($\chi^2 = 11.1$, $p < 0.001$).

Figure 2 *near here*

3.3 Color

The ability to discriminate slight hue differences was always better in the lower visual field than the upper visual field. Subject 1 was tested with three different equiluminant pairs: yellowish targets with bluish distracters, reddish targets with yellowish distracters, and reddish targets with bluish distracters. (None of the hues was very different from the neutral gray background, and all were equiluminant with that background according to the subject's determination). Every block provided a significant advantage for the lower visual hemifield (there were four blocks of yellow *versus* blue, three with 200 trials and one with only 100). The block of 100 trials had the smallest χ^2, 2.8 ($p < 0.02$); all other χ^2 for individual blocks ranged from 8.1 to over 50, all $p < 0.005$. The blocks for reddish targets, $N = 200$, had χ^2 values of 18.8 and 12.7 ($p < 0.001$).

The other two subjects were tested only for yellowish targets with bluish distracters, in blocks of 200 trials. Both subjects also performed far better for equiluminant stimuli in the lower visual field, with $\chi^2 = 44.2$ and 46.5 ($p \ll 0.001$). These results are shown in Figure 2.

Mean luminance had not seemed to be an especially effective cue to favor the lower visual hemifield, but to insure that the effect of hue was not inadvertently caused by a failure to determine precise equiluminance, a blue pedestal was added to the otherwise equiluminant disks. Pedestals would be expected to mask any slight luminance differences by reducing them to less than a *jnd*. This manipulation also rendered all the disks more visible against the gray background.

All three subjects were significantly better at discriminating target disks with pedestals in the lower visual hemifield than in the upper. The smallest value of χ^2 obtained for any subject (combining all blocks for each subject: $N = 288$, 324, and 216, respectively) was 12.0 ($p < 0.001$). Performance on these tasks can be seen in Figure 2.

As a final confirmation that luminance was not contributing to the ability to discriminate hues, a small random amount of neutral gray was added to each disk in the target, distracter, and background regions. This scrambled the luminances and saturations such that only hue could be used as a cue. Only subjects 1 and 2 were tested with this paradigm, but both showed a significant lower hemifield advantage. The values of χ^2 were 54.0 and 8.8 ($p < 0.005$) for 312 and 468 trials, respectively. These results are also presented in Figure 2. (Note that all of these trials were interlaced with trials in which the upper visual hemifields showed a significant advantage).

3.4 Depth

To test whether motion in depth might be different from discrimination of colors, solid black disks changed positions in a two-frame presentation. Motion in depth was especially interesting, since it had been shown that some motion in random dot stereograms was specifically favored in the upper visual hemifield (Breitmeyer, Julesz, and Kropfl, 1975).

Subjects 1 and 3 performed better for stimuli in their upper visual hemifields; subject 2 was unable to make the discrimination with better than chance performance in either hemifield with the short frame durations tested. The difference between hemifields was weak for subject 1, although with enough trials (1292 total) the difference was significant ($\chi^2 = 9.7$, $p < 0.002$). Subject 3 performed much better in her upper field, with $\chi^2 = 18.7$ after only 133 trials ($p < 0.001$). Their mean performances are shown in Figure 3.

Figure 3 *near here*

Subject 1 seemed to perform better when the stimuli moved toward him than when they moved away, so the tests were repeated with only forward motion of the target. Only 200 trials were attempted for subject 1, and his slight advantage in the upper field was not significant. However, subject 2 did show a significant upper field advantage with this paradigm (with the frames lengthened to 112 ms), with $\chi^2 = 5.7$ in 252 trials ($p < 0.02$). Subject 3 again showed a significant upper field advantage, with $\chi^2 = 28.4$ in 200 trials ($p \ll 0.001$).

To test whether the upper field advantage was due to motion in depth or simple detection of depth in the second frame, subjects viewed a single 280 ms frame in which the target disks appeared closer to the observer than all other disks. All three subjects showed a significant upper visual hemifield advantage in this task. The smallest χ^2 (subject 1, with 175 trials) was 12.2 ($p < 0.001$). The other two subjects showed an even greater advantage for the upper field with 200 trials each. These results are also shown in Figure 3.

3.5 Motion

If depth and motion in depth favor the upper visual hemifield, perhaps motion is a parameter better processed in the upper field. This was tested by having the target disks move laterally. In pilot work with subject 1, the distracter disks also moved laterally, but in the opposite direction from those in the target region; this proved to be a very difficult task, with no hemifield showing a significant advantage (although the lower field seemed slightly better). Similarly, holding the target disks steady while all other disks moved laterally was a difficult discrimination for which an apparent small lower field advantage did not prove significant. Therefore, the only tests performed for all three subjects were with the target disks displaced leftward or rightward while all other disks remained stationary.

Subjects 1 and 2 showed a significant advantage for detecting lateral displacements in the lower visual hemifield. Subject 1 had $\chi^2 = 4.9$ (144 trials; $p < 0.05$), and subject 2 had $\chi^2 = 7.0$ (168 trials; $p < 0.01$). Subject 3 showed a weak lower field preference, but the difference was not significant in 216 trials. Combining the three subjects, the effect was significant ($\chi^2 = 9.7$, $p < 0.002$). These results are shown by the rightmost set of bars in each group in Figure 3. It would not appear that the detection of motion in depth was due to detection of motion; indeed, the opposing effect of detecting motion better in the lower field may partially account for a weaker upper field advantage for depth in motion than for static depth.

3.6 Interlaced blocks

A possible bias affecting these results is that subjects might expect an advantage for one field or the other, either through learning or for theoretical reasons. Even though the next stimulus is equally likely to be either above or below fixation, a subject could easily favor one or the other hemifield by subconsciously directing attention or fixating slightly above or below the fixation pattern. Interlacing experiments for which the two hemifields are differently favored mitigates this possible bias, because the subject not only is unable to predict whether the next presentation will be above or below fixation, but whether it will include a stimulus favored in the upper or lower hemifield. Note that many of the results reported above were obtained from one parameter set in this interlacing paradigm; in every case, the test that was interlaced and not mentioned produced an advantage in the other hemifield from the one reported.

Interlacing two sets of stimuli was used to test the robustness of the upper field advantage of single frame displacements toward the observer and the lower field advantage of hue discrimination on a blue pedestal. The latter was chosen to represent a lower field selective stimulus because the pedestals made the disks sufficiently visible that they would not be masked by the high contrast disks used for depth on the interlaced trials.

All three subjects showed a lower visual hemifield preference for the hue discrimination task, and an upper field preference for detection of depth, in each of various blocks with slight variations of the specific parameters. Subject 1 completed four interlaced sets; in all four, the lower field had a significant advantage for color (χ^2 of at least 14.9, all $p < 0.001$; overall, for 1032 trials, $\chi^2 = 158$, $p \ll 0.001$). The upper field always displayed an advantage for depth, although the difference was not significant for one of his four blocks. Overall, however, there was a significant upper field advantage: $\chi^2 = 13.8$ for 1008 trials, $p < 0.001$. The averages of the four sets of blocks are shown in Figure 4.

Figure 4 *near here*

The other two subjects produced similar results. Subject 2 endured a block with 234 trials of each test. Performance on the hue task was significantly better in the lower visual hemifield ($\chi^2 = 8.8$; $p < 0.005$). Performance on the depth task was better in the upper field ($\chi^2 = 7.7$; $p < 0.01$). Subject 3 showed the same effects in each of five sets of interlaced blocks; the averages of the five (shown in Figure 4), a total of 360 trials for each condition, showed a significant lower field advantage for hue ($\chi^2 = 17.3$; $p \ll 0.001$) and an upper field advantage for depth ($\chi^2 = 57.9$; $p \ll 0.001$).

4. Experiment 2

4.1 Introduction to experiment 2

Given a robust effect of a lower field preference for hue and an upper field preference for depth, it was possible to vary the parameters of these two tasks to see the effects of increased difficulty upon these differences. Increased difficulty had seemed to increase the advantage enjoyed in the lower visual hemifield when that was the better field. Could this effect be replicated? If so, what would be the effect when the upper hemifield was preferred? Would difficulty enhance the lower field and thus reduce the difference, or would it increase the difference regardless of which field was preferred?

There are two ways to increase the difficulty of a task. One may either change the parameter that is being discriminated, or change an ancillary parameter. For example, to increase the difficulty of the hue task, the saturation of the target disks can be reduced; in the limit, the task becomes impossible because all disks are the same hue. Alternatively, one could reduce the effective area of the target, either by decreasing the number of disks within the target (and the density everywhere else) or by decreasing the size of all the disks.

For the depth task, the disparity can be altered; that is, the amount each target disk is displaced in the two eyes can be decreased (in the limit, the task is impossible because the disparity is zero and the target disks are in the same plane as all the others). Alternatively, the number of disks can be decreased, allowing less opportunity to detect the disparity. Note that changing disk size would not be expected to have much effect upon the task difficulty.

Subject 1 was tested in independent blocks; that is, all stimuli in a given block depended upon either hue or depth, with the same parameter for the entire block. This allowed for the possibility that he might subconsciously favor the upper or lower field. Subjects 2 and 3 had randomly interlaced blocks. In any given block, one set of hues and parameters was tested, interlaced with a set of depths at a fixed set of parameters. To minimize the possibility of an interaction with difficulty, the parameters were chosen such that the difficulties of the two interlaced tasks would be roughly equivalent. Subject 1 provided verification that any effects were not influenced by an interaction of the interlaced tasks.

4.2 Effect of difficulty on hue discrimination

Hue discrimination is better in the lower visual hemifield, so one may expect increasing difficulty to increase the difference between upper field and lower field performance. This was not the result obtained.

Difficulty was first altered by changing the saturation of the target disks, which had excess redness with a compensating decrease in green plus the blue pedestal (all other disks consisted of only the blue pedestal). As may be seen in Figure 5A, which shows the results for subject 2, performance was always better in the lower visual hemifield, except when saturation was minimal and performance in both hemifields was essentially random. The greater the red component, which generates saturation (to the right on the logarithmic *x*-axis), the larger the difference between hemifields. That is, the discrepancy between the upper and the lower visual hemifields was greater for simpler tasks, and less for the most difficult, from threshold to near saturation in the lower hemifield.

Figure 5 *near here*

One would expect a psychometric curve approximating a cumulative normal function (or a cumulative Weibull, which can be quite similar). In Figure 5, the data have been expressed as *z*-scores. Since there is a lower limit for guessing (33.3% because the task was 3 AFC), each raw percentage correct was first converted to an accuracy score that could range from 0% to 100% by subtracting 33.3% and multiplying by 3/2. The straight lines (fit by linear regression) therefore represent a cumulative normal (ogival) curve on a logarithmic abscissa. The inset shows the same data and fits expressed as percentage correct, rendering the ogival shape patent. Note, however, that the slopes of the *z*-score lines represent the steepness of the ogives, which is not obvious from inspection of the segments available in the insets. Data from both other subjects displayed the same pattern of lines converging at the lowest saturation, with the data for the lower visual hemifield rising more steeply than that for the upper field as saturation increased.

The slopes of the regression lines (*z*-scores *versus* logarithm of saturation) were normalized by dividing the abscissae by the standard deviation of the domain tested; this would allow rough comparisons when different parameters were varied. Note that the domains were nearly the same for all three subjects for any given parameter. The differences between these normalized slopes (slope in upper visual field minus that in the lower field) are presented in Table I. The first row of the table presents the differences for all three subjects when saturation was varied; the right column gives the average of the three subjects, and the italicized values are derived from Figure 5A. The negative differences mean the lower visual hemifield had the steeper slope.

Table I *near here*

A different pattern emerged when difficulty was adjusted by a parameter other than that which was to be discriminated. Figure 5B shows the results from the same subject when the hues were held constant but the diameters of the disks varied. Larger diameter disks provide greater area and coverage, so the subtle hues are more easily discerned when the disks are larger.

It is clear in Figure 5B that for any disk size, the lower visual hemifield held an advantage over the upper field. Since the *z*-score for 100% is infinite, the highest point in the lower field (visible in the inset) could not be used. The regression lines are very nearly parallel; insofar as there is a slight convergence, it is as the disks are smaller. A lateral shift implies a difference in sensitivity.

The other two subjects displayed this same pattern, with lines that were very nearly parallel. The next row of the table presents results for changing the sizes of the disks. The small numbers mean the regression lines were essentially parallel. The italicized entry was derived from Figure 5B. Subject 1 was also tested with changes in density of the disks (number within the target), with comparable results (essentially parallel functions).

4.3 Effect of difficulty on depth detection

Depth detection is better in the upper visual hemifield; would this upper field advantage change with difficulty, and, if so, in what way?

Figure 6A shows the effect of changing the disparity of the target disks by various amounts for subject 1. The pattern is similar to that observed in Figure 5A when saturation was adjusted. However, in this case, the upper visual hemifield provided the better performance (except when disparity approached zero, for which no detection was possible in either hemifield). As was the case for hue, performance in the preferred field rose more steeply as disparity increased (difficulty decreased). The same pattern was observed for the other two subjects, as may be appreciated from the first row in the lower part of the table. A large positive number means the upper field data were fit by a much steeper line than were the lower field data. Note that in all cases in which there was a large difference (positive or negative) the steeper line was above the shallower, indicating the two lines converged when the task became difficult. The italicized entry was derived from Figure 6A.

Figure 6 *near here*

Finally, what is the effect of changing difficulty of depth detection through a parameter other than apparent depth? By increasing the number of disks in the target area, the task could be made easier, as there are more possible points at which the disparity can be detected. The effect of this manipulation was comparable to the effect of changing disk size in hue discrimination: in this case, performance in the upper field was consistently better than in the lower, but the data from both fields were fit with lines that were very nearly parallel (Figure 6B). Consistent results were obtained from both other subjects (bottom row in the table; italicized entry from Figure 6B).

5. Discussion

5.1 Experiment 1

Experiment 1 showed that different discriminations can favor the upper or the lower visual hemifields with the same task in essentially the same display. There was a robust lower hemifield preference for hue discrimination, but a similar display of disks produced a convincing upper hemifield preference for stimuli that differ in apparent depth.

This finding suggests that the lower field preference reported by others is not simply due to finer selective attention in the lower field, as has been suggested. The displays for both demonstrations were the same size, in the same positions, using the same apparatus, with the same numbers of similar disks randomly arrayed in each. In both cases, the task was to find the small spatial grouping of disks that differed from those in the rest of the display. That these findings persisted when the two tasks were randomly interleaved demonstrates that there had been no particular bias to direct gaze or attention differently depending on the task.

Nearly all stimuli tested were discriminated better in the lower visual hemifield. Those that seemed most robust (although there was no attempt to rate the relative efficacies of the various kinds of stimuli) were those that depended on color discriminations. A lower field preference was found for nearly equiluminant disks, and disks of differing hue on a blue pedestal. Since adding random luminances to each disk did not disrupt this effect, hue must be the relevant parameter. The random increments would disrupt both luminance and saturation information.

Discrimination of low contrast disks that were either slightly darker or slightly lighter than the background was also better in the lower field, although the effect was not as consistent. It is unclear whether to interpret this task as a color discrimination task (shades of gray), or a direction-of-contrast discrimination task (positive *versus* negative polarity). Detection of lateral motion of a small subgroup of disks was also somewhat better in the lower visual field, although the differences between upper and lower fields were small and somewhat inconsistent.

Detection of depth, represented by disks having crossed disparity, was better in the upper visual hemifield. Detection of motion in depth (disks jumping forward from the plane of the other disks) also was better in the upper field, but this may represent the detection of depth in the second frame. That motion is not a key element may be deduced from the fact that lateral motion is better detected in the lower visual field, and since the detection of depth in motion was less convincingly preferred in the upper field than was simple depth, it is probable that the motion slightly counteracted the effect of detection of depth.

These results generally agree with work published by others. Manning et al. (1987) reported that crossed disparity is better detected than uncrossed, although without a strong upper or lower field bias. On the other hand, Breitmeyer *et al.* (1975) found uncrossed disparity to be better in the upper field and crossed in the lower; the eccentricities used, however, were less than one degree. Lateral motion was found to be better in the lower field in a visually guided pointing task (Danckert and Goodale, 2001), who also found the lower visual field benefited more when difficulty was decreased by increasing target size. Note that their eccentricity was about half of that used here, and the dependent measure was pointing speed (or duration of the motion), not detection of position.

5.2 Experiment 2

Experiment 2 provided a further indication that the hemifield difference is not secondary to an ability to focus attention better in the lower visual hemifield. If the difference depended upon attention, more difficult tasks would be expected to show a greater lower field preference than simpler tasks of the same type. In fact, there was no such effect within the range in which performance was not limited by chance or perfection. Rather, the two hemifields showed somewhat different gains and sensitivities. Whether the preference increased or decreased could depend upon the convergence of these functions at the low and high ends of their ranges.

When the relevant parameter to be discriminated was adjusted, the lines representing the upper and lower visual hemifields converged for the weakest stimuli; in the limit, performance must be at 33.3% for either hemifield. Similarly, the functions must converge at the highest levels, as performance above 100% is impossible. These tests simply were not extended to high enough values that the poorer field approached that limit. The differences in slope, however, mean that the psychometric functions are different for the two hemifields, which presumably represents a difference in gain, not just sensitivity.

When an orthogonal parameter was adjusted, parallel lines were obtained. Because these plots have logarithmic abscissae, a lateral shift represents multiplication of the relevant parameter, which represents a difference in sensitivity between the two hemifields. The sensitivity difference would be determined by the magnitude of the parameter to be discriminated.

What might a difference in attention be expected to do to these functions? If increased attention simply increased the ability to discriminate near and below threshold, the attention-enhanced function would be shallower than that not enhanced, contrary to our findings in Figure 5A and Figure 6A. If attention improved the signal-to-noise ratio by enhancing the signal, it would increase sensitivity; one would expect the lateral shifts we obtained in Figure 5B and Figure 6B but not in the corresponding parts A. If attention boosted the signal-to-noise ratio by decreasing the noise, one would expect the psychometric function to become steeper, as in Figure 5A and Figure 6A but not in the corresponding parts B. Attention should not discriminate among parameter types, so the same effects, whatever their form, should have been evident in both part A and part B of these two figures. The differences between the two parts of each figure therefore attest that attention is not the determining factor for the superiority of one hemifield over the other. Of course, this does not mean attention plays no role in these effects, nor that it could not be the dominant factor for other tasks in which the hemifields differ.

5.3 Interpretation

It is tempting to attribute lower visual field preference to the parvocellular system, and upper field preference to the magnocellular system. After all, color is generally processed by the parvocellular system. However, the discrimination of light or dark contrasts, which might be parvocellular, could instead be mediated by the magnocellular system’s greater sensitivity to very slight contrasts. Similarly, the detection of depth, which was the only attribute clearly discriminated better in the upper visual hemifield, would be expected of both the parvocellular and magnocellular systems. Lateral motion, which might be better in the magnocellular system, could contradict an interpretation that these effects reflect differential representation of the parvocellular and magnocellular systems. Of course, the extent and speed of motion might determine whether it is better detected by one system or the other; it might also determine whether the upper or lower field would be the better performer. It is essential to note the possibly critical effects of such parameters as the particular stimuli, eccentricity, and the response task.

Another distinction that could be invoked is whether the dorsal or ventral processing streams contribute differentially to the upper and lower visual hemifields (Previc, 1998). Further experimentation would be needed to tease apart the roles of these systems.

Whatever are the distinctions that contribute to these field differences, they may be seen to make some ecological sense (Previc, 1990). The lower visual field is where the hands (or paws) work at fine tasks like separating seeds and peels from fruit, or capturing small prey. Fine color and contrast discriminations would be important for such tasks, as would sensitivity to small lateral motions. The upper field may be somewhat more concerned with approaching dangers: low tree branches, swooping predators. Recognition of depth could be important to avoid these threats. It is reasonable to assume our visual systems have evolved to meet these needs. Of course, all visual skills are valuable in both hemifields, and the subtle advantages we have shown should not be taken as implying a segregation of visual functions.

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Figure legends

Figure 1: Sample stimulus. The two halves of the image were superimposed by a stereoscope. The background was gray, not white, and extended as far below fixation as above. Disks in the target region could differ from all other disks in luminance, hue, disparity (apparent depth), or motion between two successive frames. In this exemplar of an upper visual field stimulus, the target region (rightmost position, enclosed for illustration by a dashed circle) is slightly in front of the plane of the other disks.

Figure 2: Performance of the three subjects at discriminating disks that differ from each other in lightness or hue. Disk diameter = 43.6 min; 125 total disks; 280 ms presentation. Upper visual hemifield presentations for each subject are shown by white bars, lower visual field by gray bars. Significant differences ($p < 0.025$) between upper and lower visual fields are indicated by asterisks. The dashed line at 33.3% is the performance expected for guessing. Error bars represent 95% confidence intervals. Left bars in each set: light disks = 23.4 Cd/m^2, dark disks = 24.8 Cd/m^2 (approximately ± 3% from background gray). The succeeding sets of bars for each subject represent discrimination of equiluminant disks, discrimination of equiluminant disks on blue pedestals, and discrimination of disks with blue pedestals plus a random added gray component of up to 2.6 Cd/m^2, or about 11% (not tested for subject 3).

Figure 3: Performance of the three subjects at discriminating depth (disparity) or motion. The leftmost set of bars for each subject represents discrimination of depth in motion, where the target could be in either crossed or uncrossed disparity in the second frame (subject 2 could not make these discriminations). Succeeding sets show motion of the target disks toward the subject (subject 2 had twice the frame duration as the other two subjects), simple displacement toward the subject in a single 280 ms frame, and lateral motion. Conventions as in Figure 2.

Figure 4: Performances in the upper and lower visual hemifields of the three subjects tested with randomly interlaced trials of hue discrimination and depth discrimination. Disk sizes ranged from 27 to 71 min in diameter; number of disks in the target ranged from four to eight. 280 ms presentations. Hue targets had 7.3 Cd/m^2 red with the blue pedestal; other disks in hue discrimination consisted of just the blue pedestal on background gray. Conventions as in Figure 2.

Figure 5: Effect of difficulty on hue discrimination in the upper and lower visual hemifields. Upper hemifield indicated by open squares, with linear regression shown by a light line; lower field indicated by solid triangles and a heavy line. Data of Subject 2. Seven disks in target (168 total in the display); 280 ms presentation. Percent correct converted to *z*-scores after subtracting the expected "random" performance (33.3%), and multiplying by 3/2. Abscissae scaled logarithmically. **A**. Saturation of disks in the target region was the independent variable, as indicated by the amount of red added to generate a mixture that was equiluminant with the background but for the added blue pedestal. Disk diameter = 43.6 min. Lines are regression fits to *z*-scores *versus* added red (Cd/m^2). **B**. Diameter of disks was the independent variable. Luminance of red = 7.3 Cd/m^2. **INSETS**: Same data and fits plotted with percentage correct as the ordinates.

Figure 6: Effect of difficulty on depth perception in the upper and lower visual hemifields. Data of Subject 1; conventions as in Figure 5. Disk diameter = 38.1 min; all disks black (0.1 Cd/m^2); crossed disparities; 280 ms presentation. **A.** Disparity of target disks was the independent variable; 125 total disks. **B.** Number of disks in the target area was the independent variable; total number of disks was 24 times the number in the target area. Displacement of 19.1 min in each eye.

Table I: Differences in normalized slopes of *z*-scores between Upper and Lower Field

	Subject 1	**Subject 2**	**Subject 3**	**Mean**
Hue discrimination				
Change saturation	– 0.43	– *0.98*	– 0.52	– 0.645
Change size	0.00	– *0.08*	– 0.16	– 0.080
Depth detection				
Change disparity	*0.40*	0.56	0.47	0.476
Change number	– *0.12*	– 0.22	0.05	– 0.099

Figure 1: Stimulus (rotated 90° - top is to left)

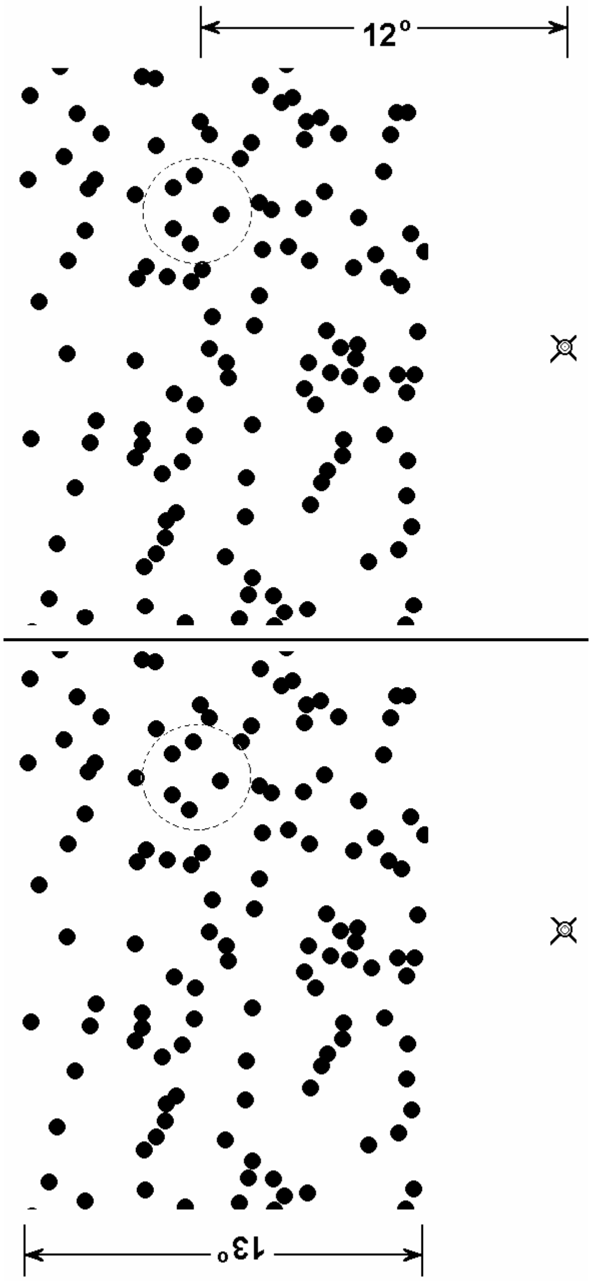

Figure 2: Luminances - colors

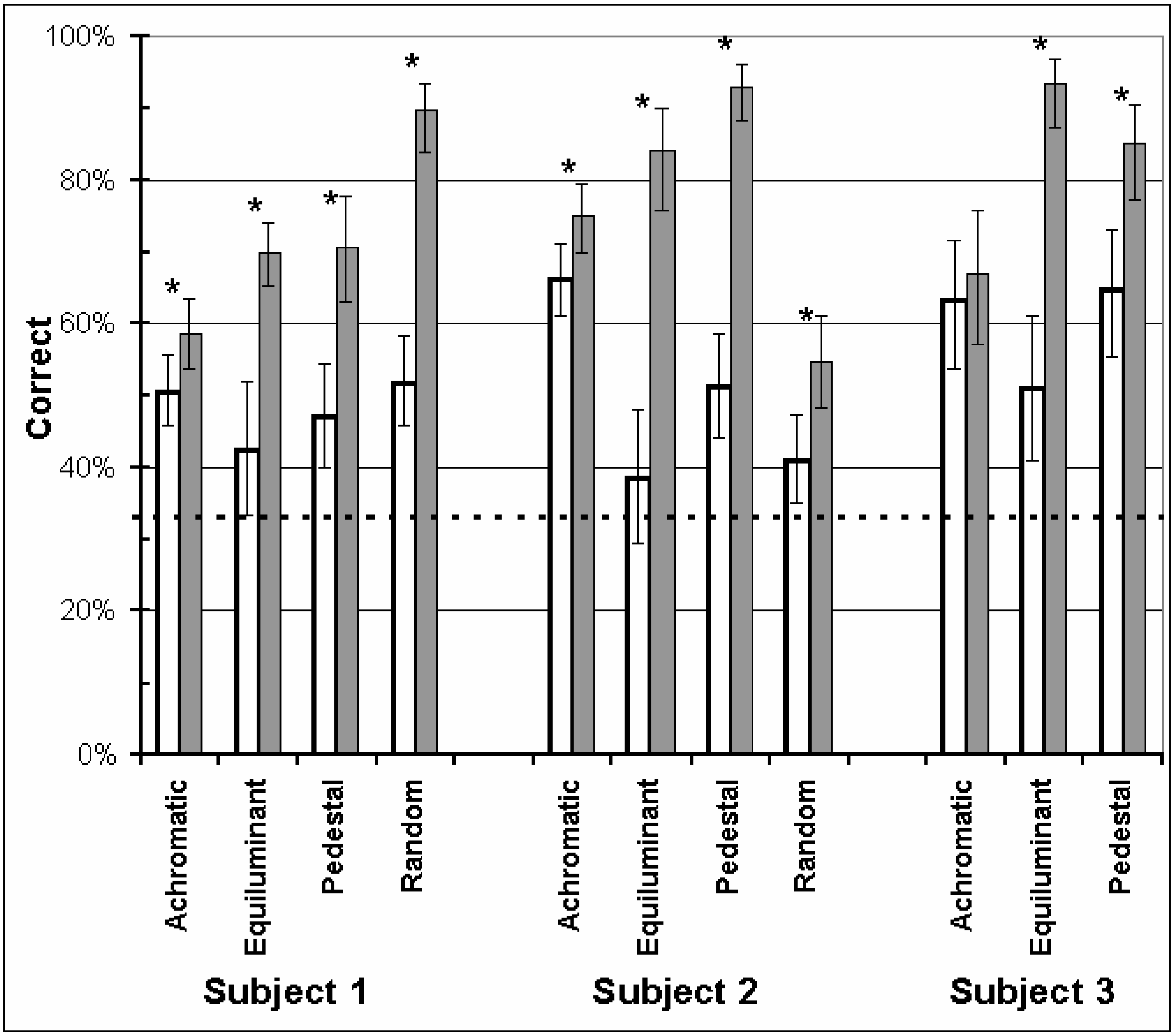

Figure 3: Depth - motion

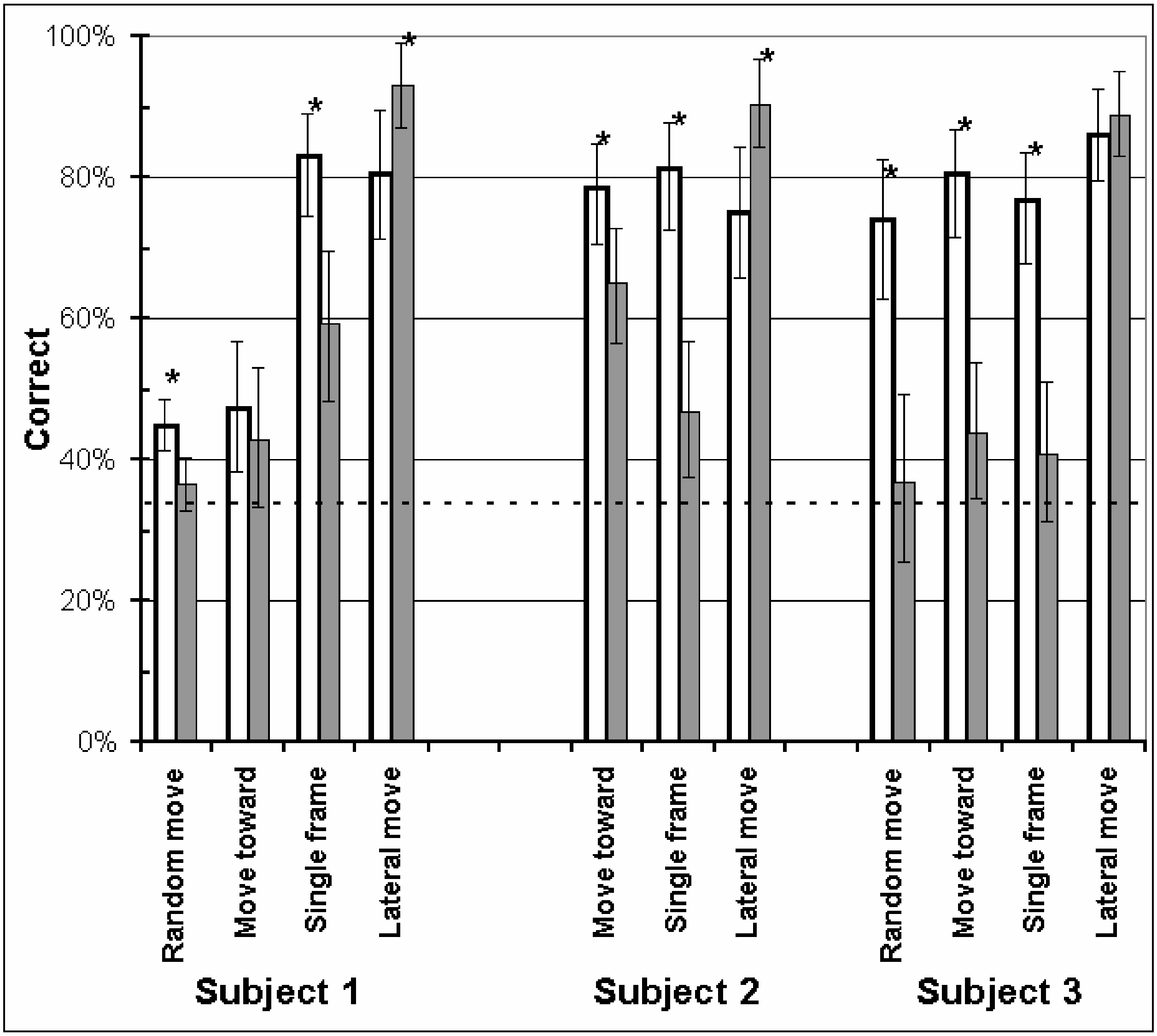

Figure 4: Interlaced

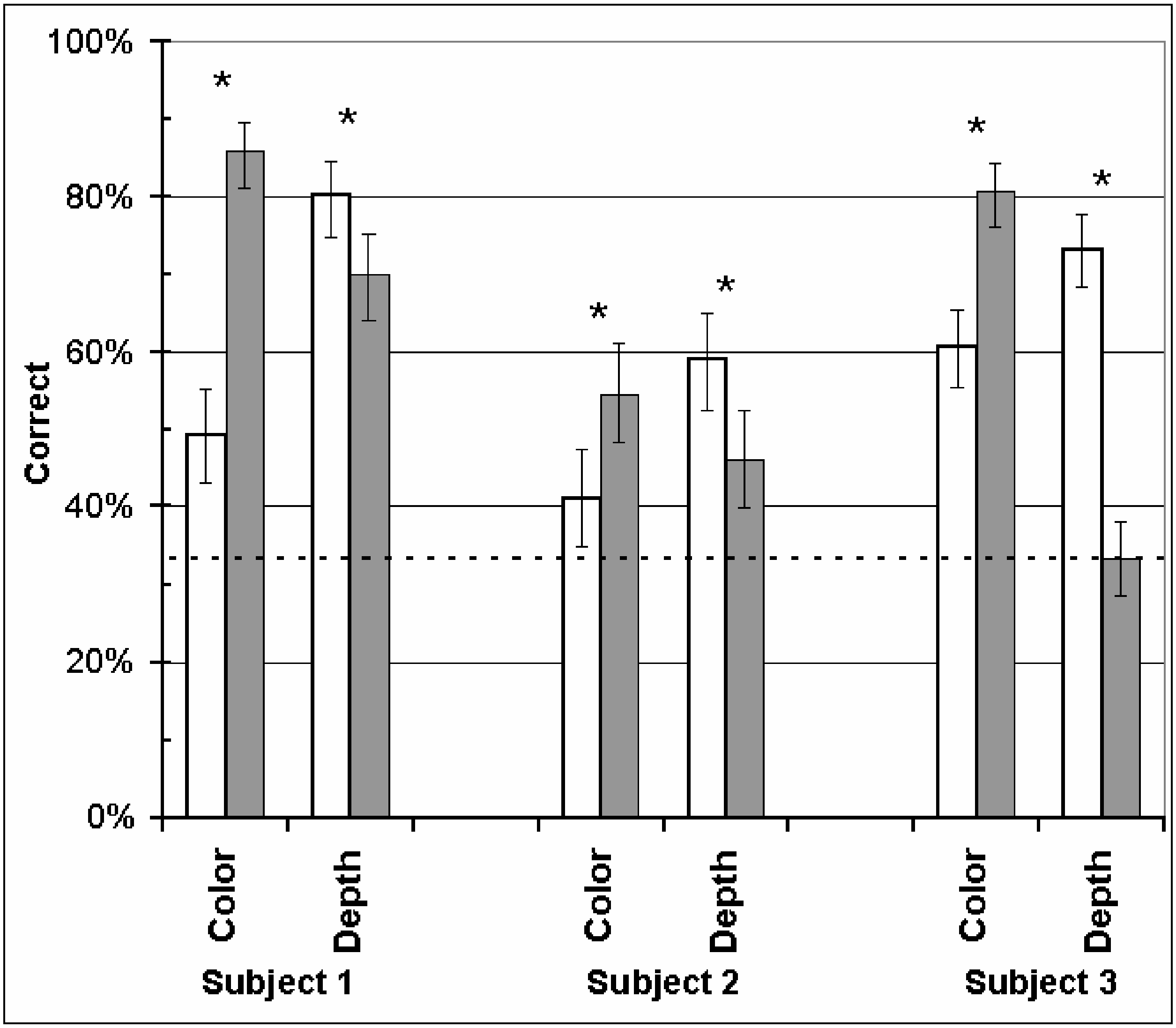

Figure 5: Color difficulty

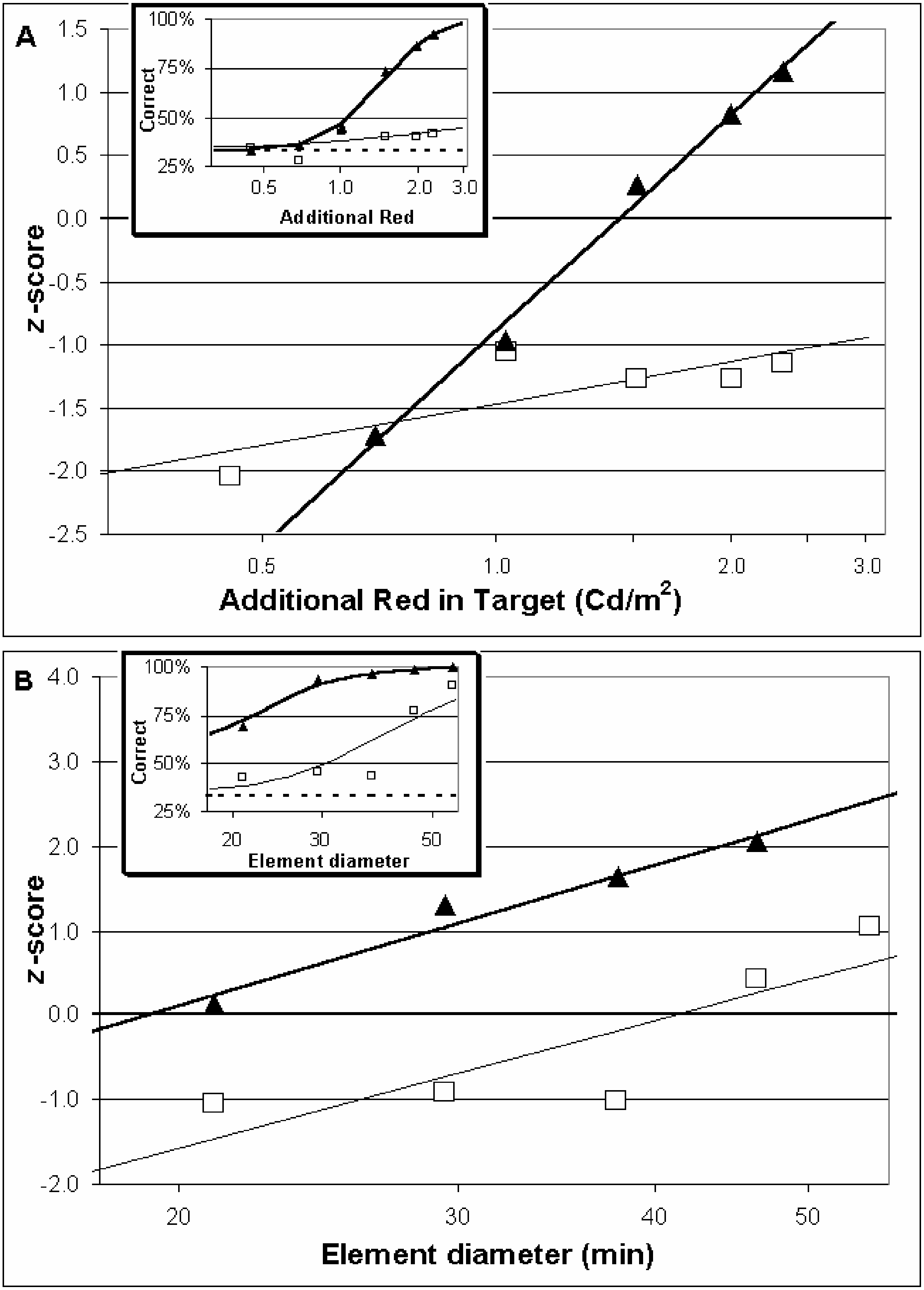

Figure 6: Depth difficulty