The highs and lows of magnocellular and parvocellular processing

J. Jason McAnany

&

Michael W. Levine

Department of Psychology,
University of Illinois at Chicago, Chicago, IL.

Introduction

- A number of investigators have shown that complex stimuli presented in the lower visual field (LVF) are more easily detected than the same stimuli presented in the upper visual field (UVF)*.
- UVF superiority has been found for some serial searches, but that could be explainable by the tendency to read left-to-right, top-to-bottom.

*See review by J.A. Danckert & M.A. Goodale (2003), in *Taking Action*. S.H. Johnson (Ed). MIT Press. pp. 29-64.

- While some LVF superiority may be attributable to a slightly denser ganglion cell distribution in the superior retina, the prevailing explanation of this difference suggests that **attention** is more finely focused in the LVF.
- Our studies of the blanking phenomenon (presented at VSS 2002 and 2003) seemed to confirm that greater LVF superiority was obtained with more "**difficult**" stimuli. A scatterplot of the relative thresholds of UVF *versus* LVF as a function of mean threshold (as an indicator of difficulty) is shown in Fig. 1.

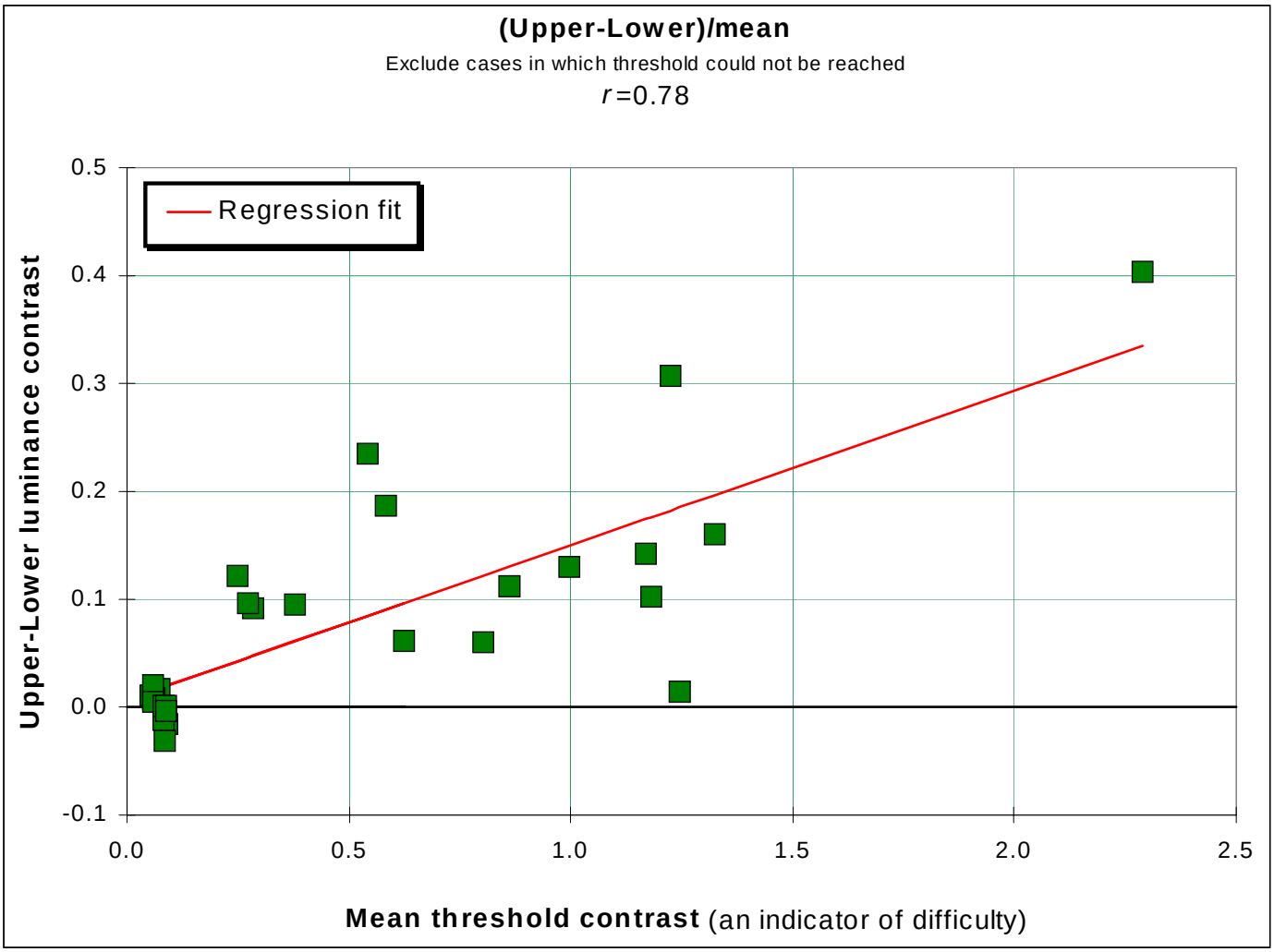


Fig. 1: Scatterplot of "contrast" between detection thresholds for upper visual field (UVF) and lower visual field (LVF), taken as the threshold difference over the threshold sum, *versus* mean contrast threshold. Thresholds are for detection of disks either lighter than or darker than the background gray, in the presence of a grid of squares of black, white, or gray (no squares).

Data from McAnany & Levine, *Vision Research* **44**; 993-1001.

- In this series of experiments, we explored whether performance in the UVF can be better than in the LVF for tasks comparable to the detection tasks that favor the LVF.
- We also asked whether “difficulty” is a factor in determining LVF superiority. In particular, if the UVF were better in a particular task, would increased difficulty reverse the effect and favor the LVF, or would it enhance the superiority of the UVF?
- We used a detection experiment in which a field of disks appeared briefly either above or below fixation. The subject had to find which of three patches of disks differed from the others (3AFC).

Methods

- The subject had to detect a cluster of disks (the **target**) that were different in some predetermined way: color, luminance, apparent depth, etc. In most cases, two different classes of stimuli were randomly interlaced (i.e.: difference in depth and difference in color).
- Stimuli were presented in stereoscopic view.
- Two typical arrays of disks are shown in Fig. 2. A new random array was generated for each presentation, but the number of disks in each portion of the pattern was constant in any series.
- In the figure, the target section is shown as red disks in the center position of a field of green distracter disks (upper display), or the left position (lower display). Actual stimuli were far more subtle (see Fig. 3).
- The target could have been left, center, or right; the entire array could appear either above or below fixation (**not** both, as in Fig. 2). All possible positions occurred an equal number of times in a random series of 120 - 180 trials. Stimuli were presented for 280 msec; between trials, the field was the same gray as the array background (3.77 ft-Cd/cm^2). The fixation object was always present.
- The subject indicated the position of the target (left, middle, right) with a key press and then initiated the next trial.
- Subjects were both male (ages 24 and 61), with vision corrected to normal and no known color anomalies.

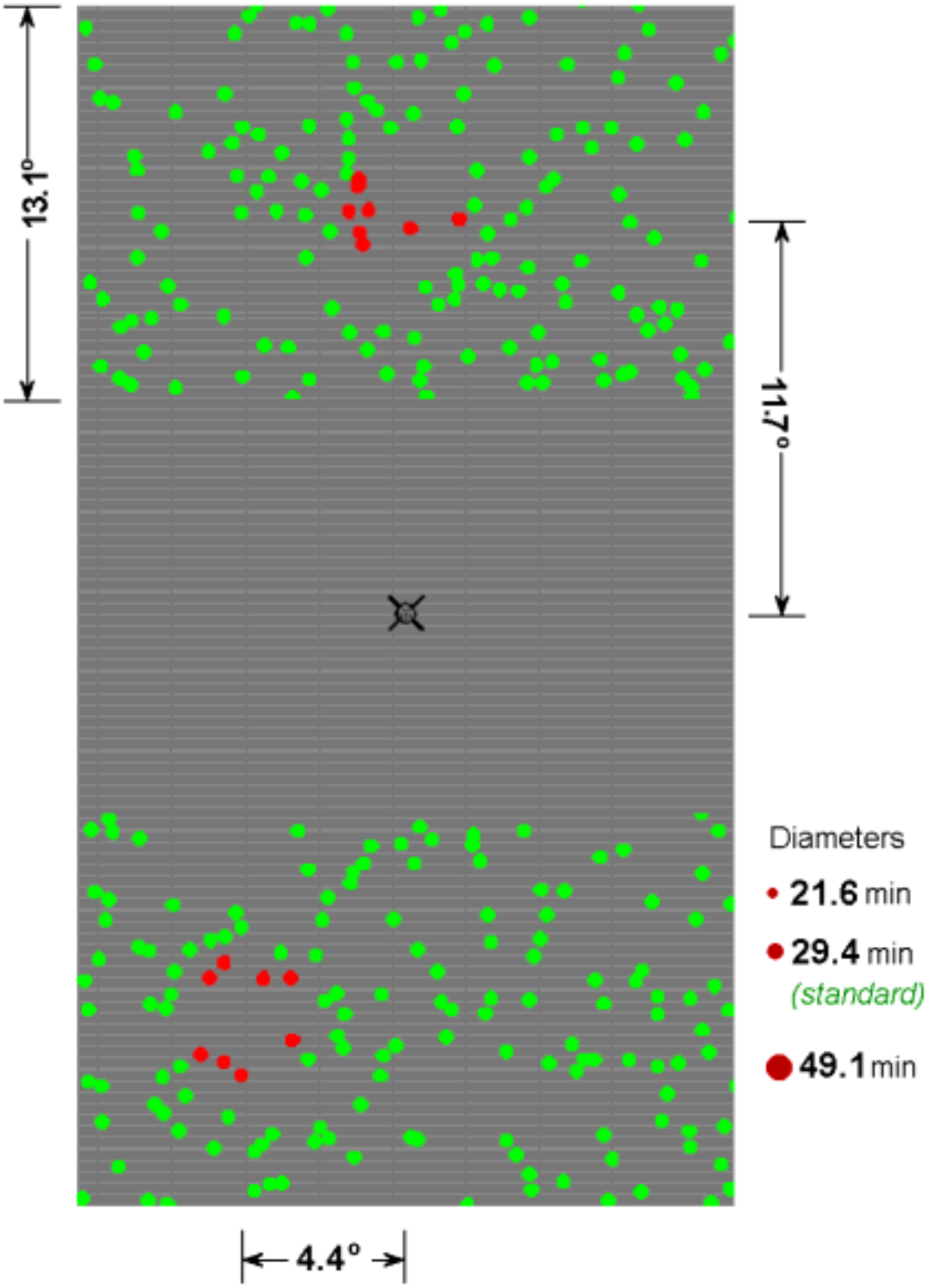


Fig. 2: Stimulus layout and dimensions.

Note that when the target was in the upper field, the lower field was blank (and vice versa).

Color *versus* Depth

- One kind of discrimination is based on color (hue). Three cases were tested:
  - ✓Stimuli equiluminant with each other and with the background gray (e.g.: Fig. 3a).
  - ✓Equiluminant stimuli on a pedestal so both target and distracters are brighter (and bluer) than the background (e.g.: Fig. 3b).
  - ✓Stimuli on a pedestal but with random increments or decrements of gray added to each so brightness cannot serve as a cue (e.g.: Fig. 3c).
- Another kind of discrimination is the relative depth of target disks. Fig. 3d indicates one group of disks appearing in front of the distracter disks.

Fig. 3a: An array in which the target disks differed from the distracters only in hue. All disks were made **equiluminant** with the background gray (printing inks do not faithfully represent the hues and luminances).

Equiluminance pairs were pre-determined by having the subject adjust the foreground and background colors of a high contrast photograph (e.g.: a Mooney face) until it could not be judged whether the picture was a positive print or a negative.

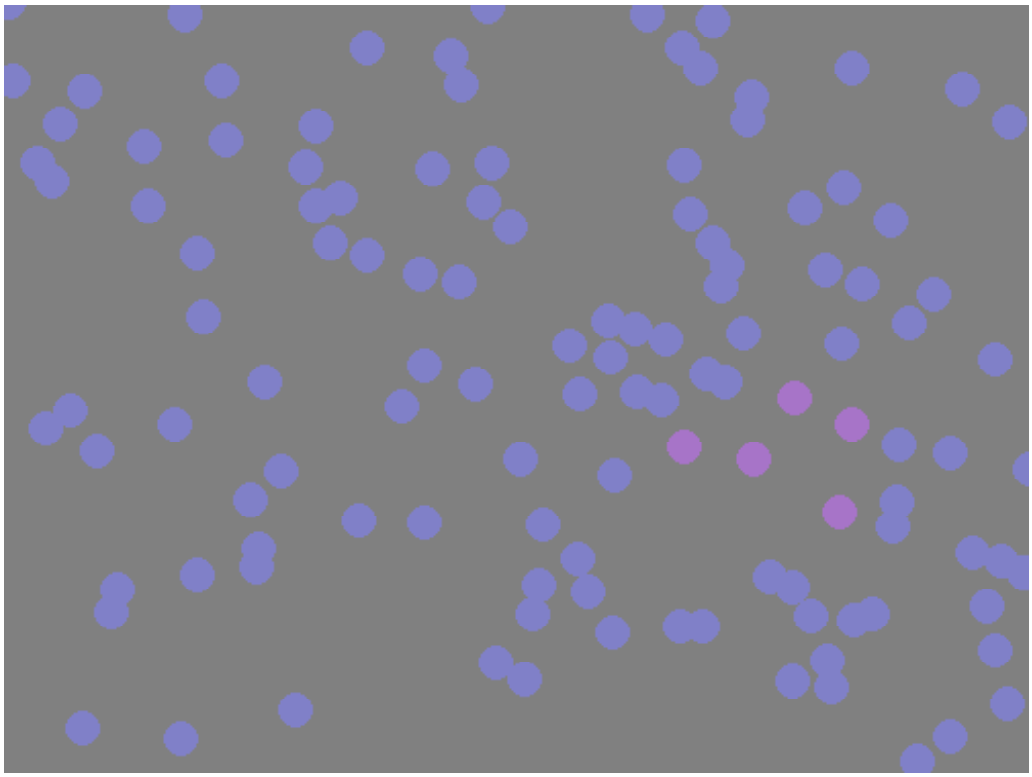


Fig. 3b: An array in which the target disks differed from the distracters only in hue. A desaturated red/green equiluminant pair was selected, but each was boosted in luminance by adding a blue **pedestal**.

The subject was aware of what hue would be the target, and what was the distracter, although both were brighter and bluer than the background gray.

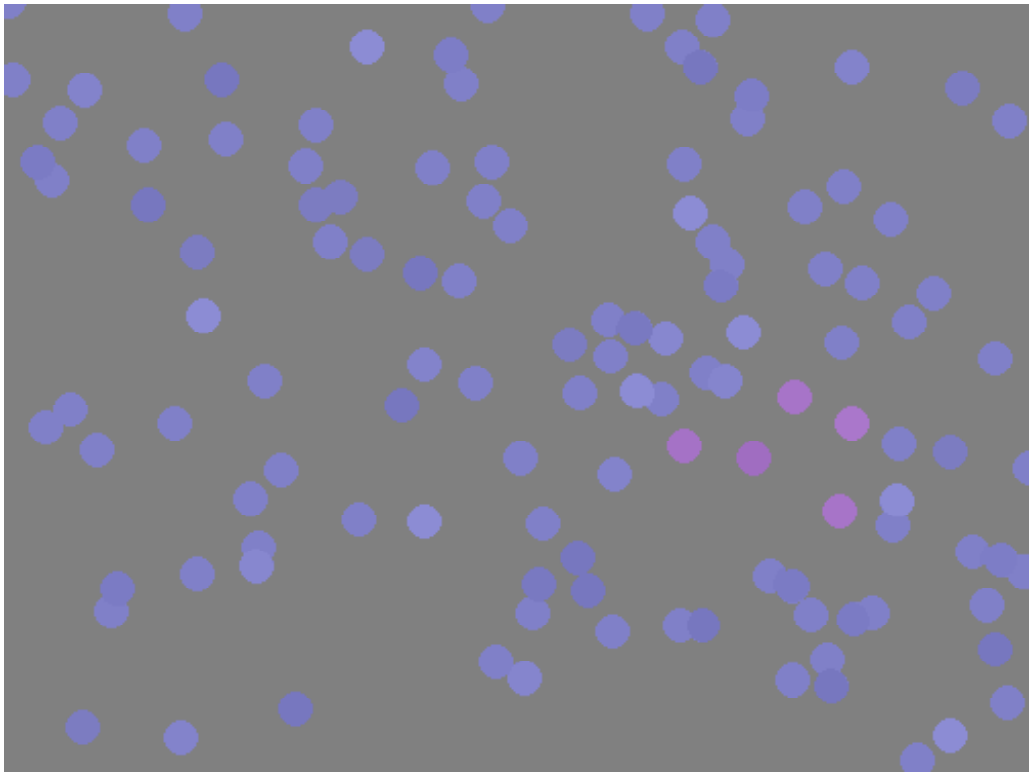


Fig. 3c: An array in which the target disks differed from the distracters only in hue. An equiluminant pair was selected, and the identical blue pedestal was added to each disk.

However, to further insure that brightness was not a cue, each disk (both in the target region and the distracters) was randomly adjusted by adding or subtracting a random amount of gray. Thus, the target disks differed from the distracters in hue, but each disk had a **random luminance**.

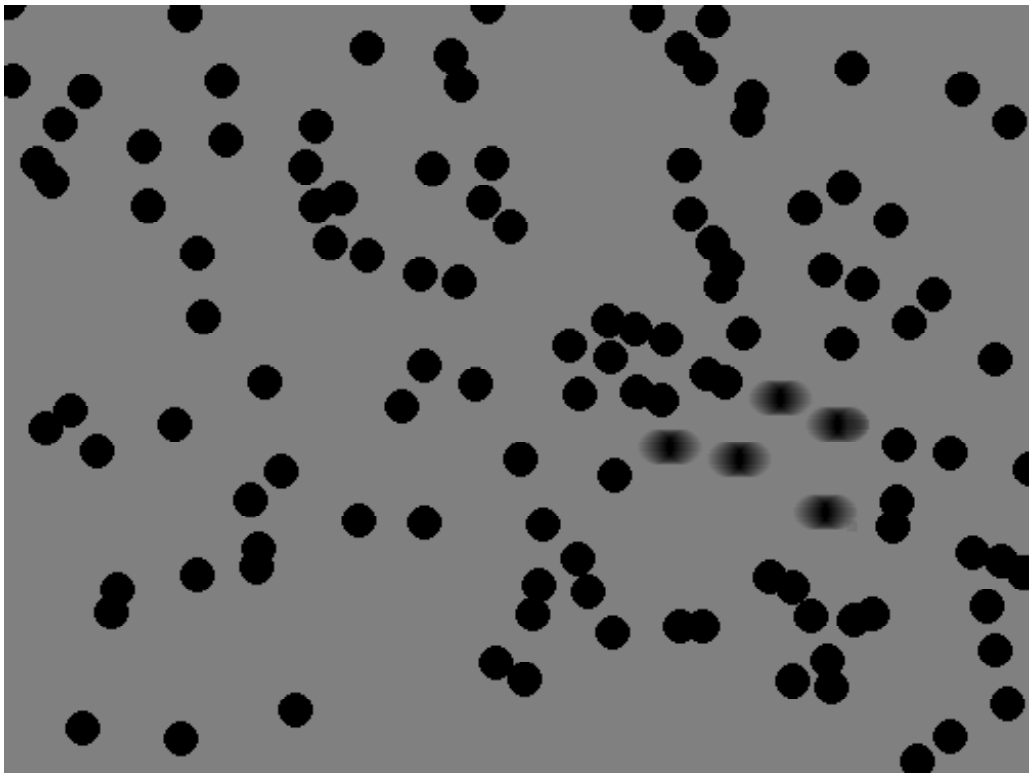


Fig. 3d: An array in which the target to be detected is displaced in **depth**. (The displaced set of disks, represented by blurring, is in the "rightward" position).

In the experiments reported here, displacement was always toward the observer; that is, the target disks appeared to lie in a plane in front of the distracter disks (crossed disparity). Depth is expressed in degrees of disparity between the left and right eyes.

Each disk's position was adjusted for the subject's horopter (measured by the Nonius method). Control series in which the horopter correction was omitted or reversed yielded comparable results.

Color discrimination is better in the LVF

- When any of the color discrim-ination tasks is interlaced with a depth series, the subject scores better on the color task in the LVF (red bars) than the UVF (blue bars); see Fig. 4.
- Discriminations based solely on the lightness of the target disks (using only grays) are also superior in the LVF (Fig. 4, rightmost group).

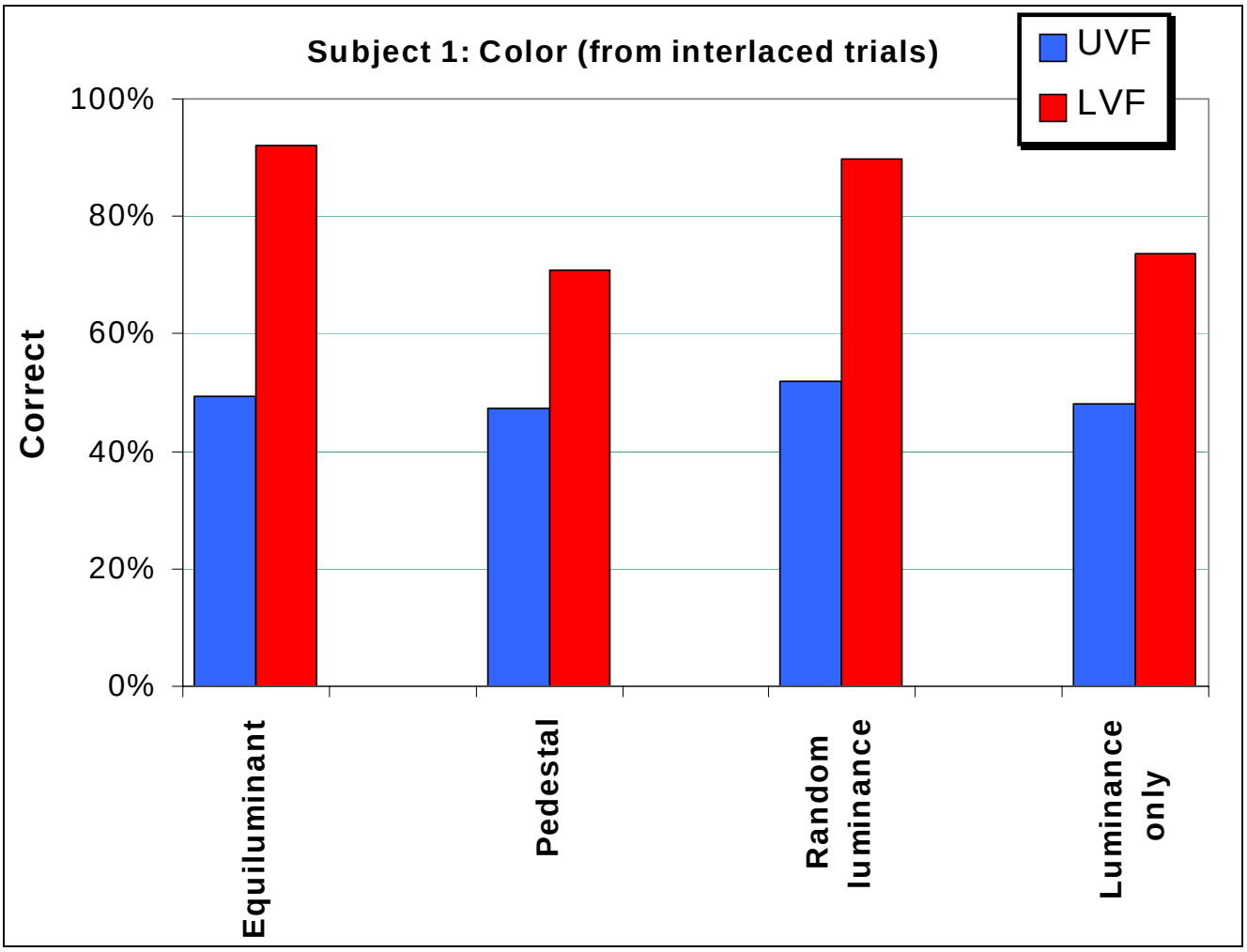


Fig. 4: Upper visual field (UVF) *versus* lower visual field (LVF) performance on discrimination of differences in color or luminance for one subject. All these differences were significant ($p < 0.01$).

These trials were randomly interlaced with depth trials to ensure the subject did not bias the results by knowing the lower field “should” be better for color. Performance on the interlaced depth trials was significantly better in the UVF.

Depth discrimination is better in the UVF

- Subjects did better on trials in which the target appeared in front of the distracter plane (Fig. 3d) when the stimulus was in the UVF. Figure 5 shows the comparison of all color discriminations *versus* depth discriminations for both subjects.
- Differences between UVF and LVF were significant on individual runs as well as overall (Fig. 6).

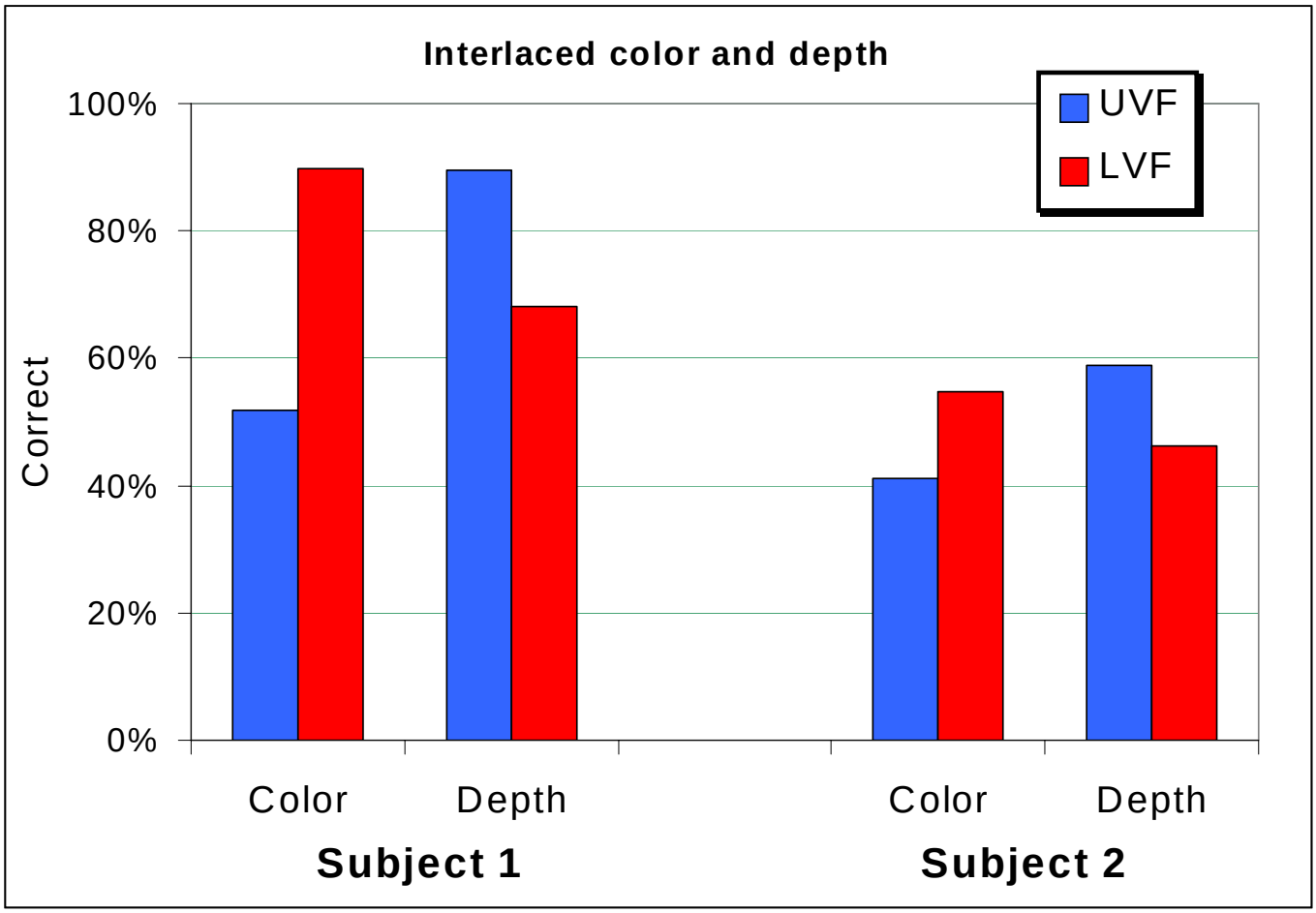


Fig. 5: Upper visual field (UVF) *versus* lower visual field (LVF) performance on differences in color *or* differences in apparent depth for both subjects.

Color and depth trials were randomly interlaced, so the subject never knew whether to expect a stimulus in the upper or the lower field, or whether the target would differ in color or in depth. The requirement was clear upon presentation, because the depth stimuli had only solid black disks, while color stimuli were of lower contrast with a distinct bluish hue.

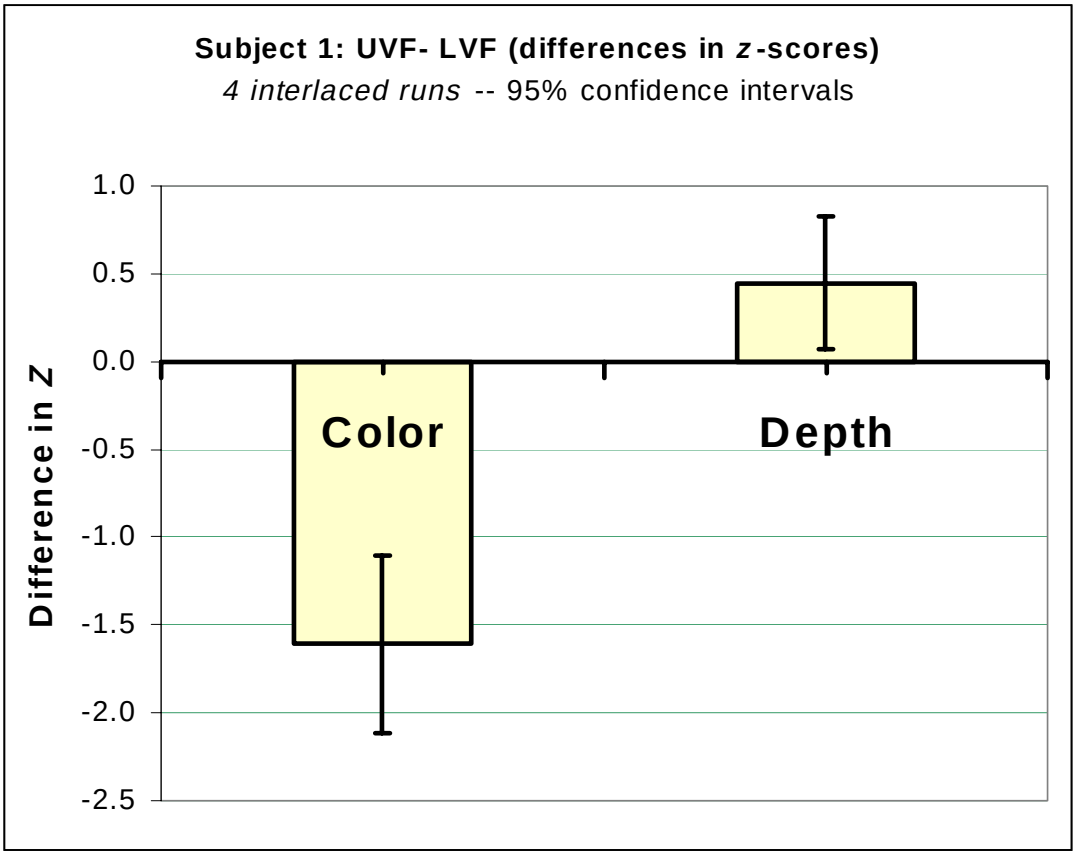


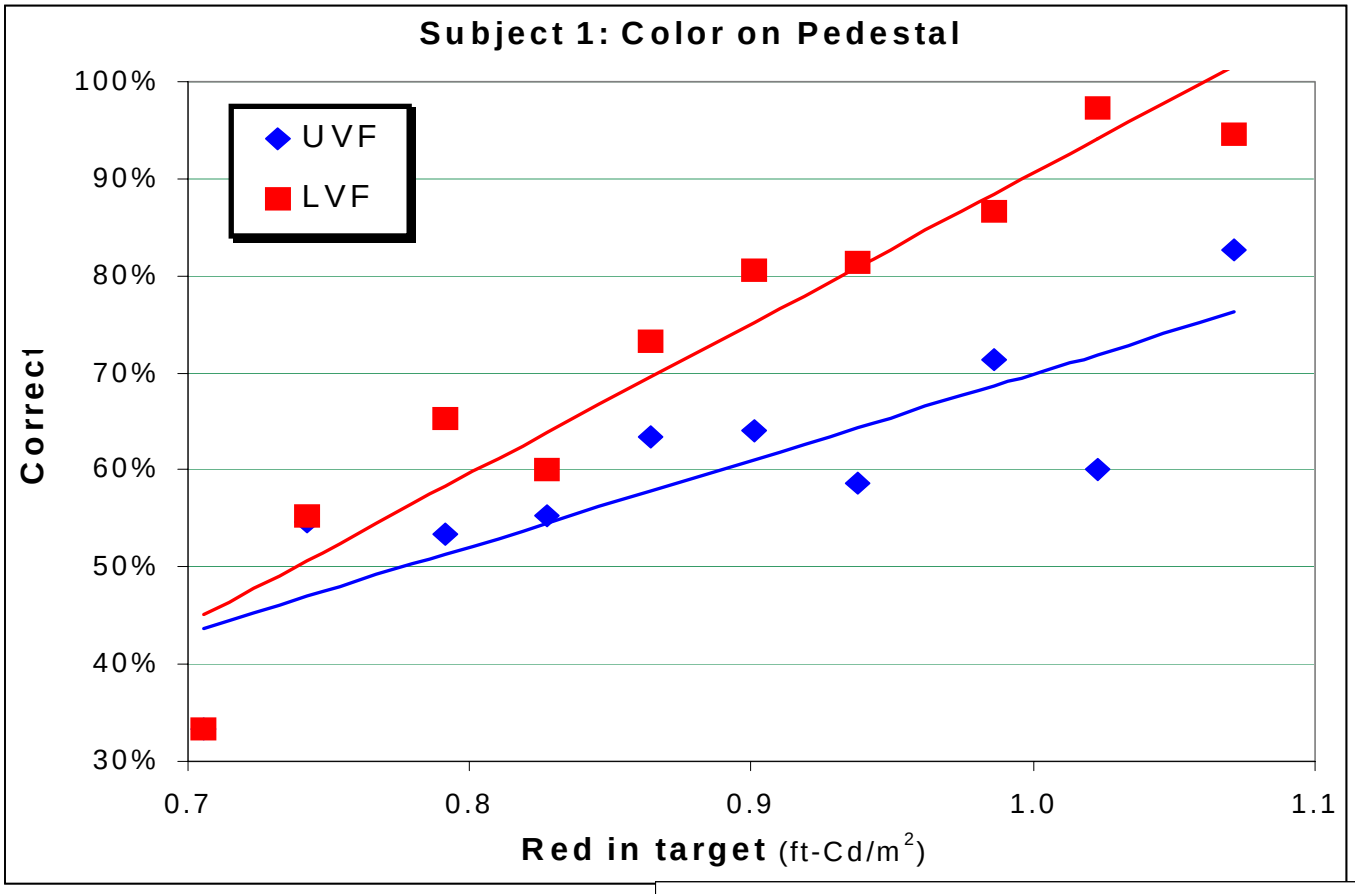
Fig. 6: Upper visual field (UVF) *versus* lower visual field (LVF) performance on differences in color (equiluminant, pedestal, and random luminance) *or* differences in apparent depth.

For each run, the percentage correct was converted to a corresponding *z*-score after subtracting 33.3% (for random guessing) and multiplying by 3/2. The difference ($z_{UVF} - z_{LVF}$) was found for each run; the graph shows the mean differences, with 95% confidence error bars.

In all individual runs, the UVF/LVF differences were significant ($p<0.05$) for both color and depth (by chi square tests).

Does difficulty affect the UVF / LVF balance?

- For either depth discriminations or color discriminations, tests were performed at varying levels of difficulty.
- Difficulty could be varied by changing the parameter that is to be discriminated — saturation for color (Fig. 7) , disparity for depth (Fig. 9).
- Alternatively, difficulty could be varied by changing a secondary parameter — number or size of disks in the display (Figs. 8 & 10).



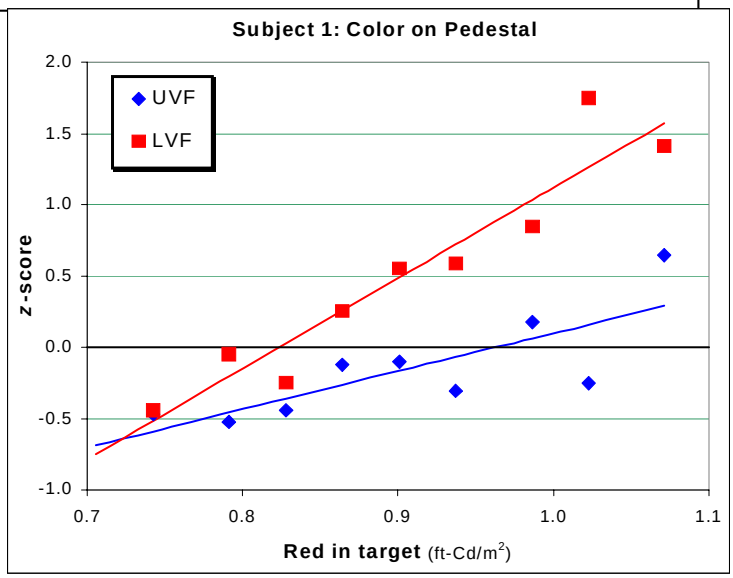
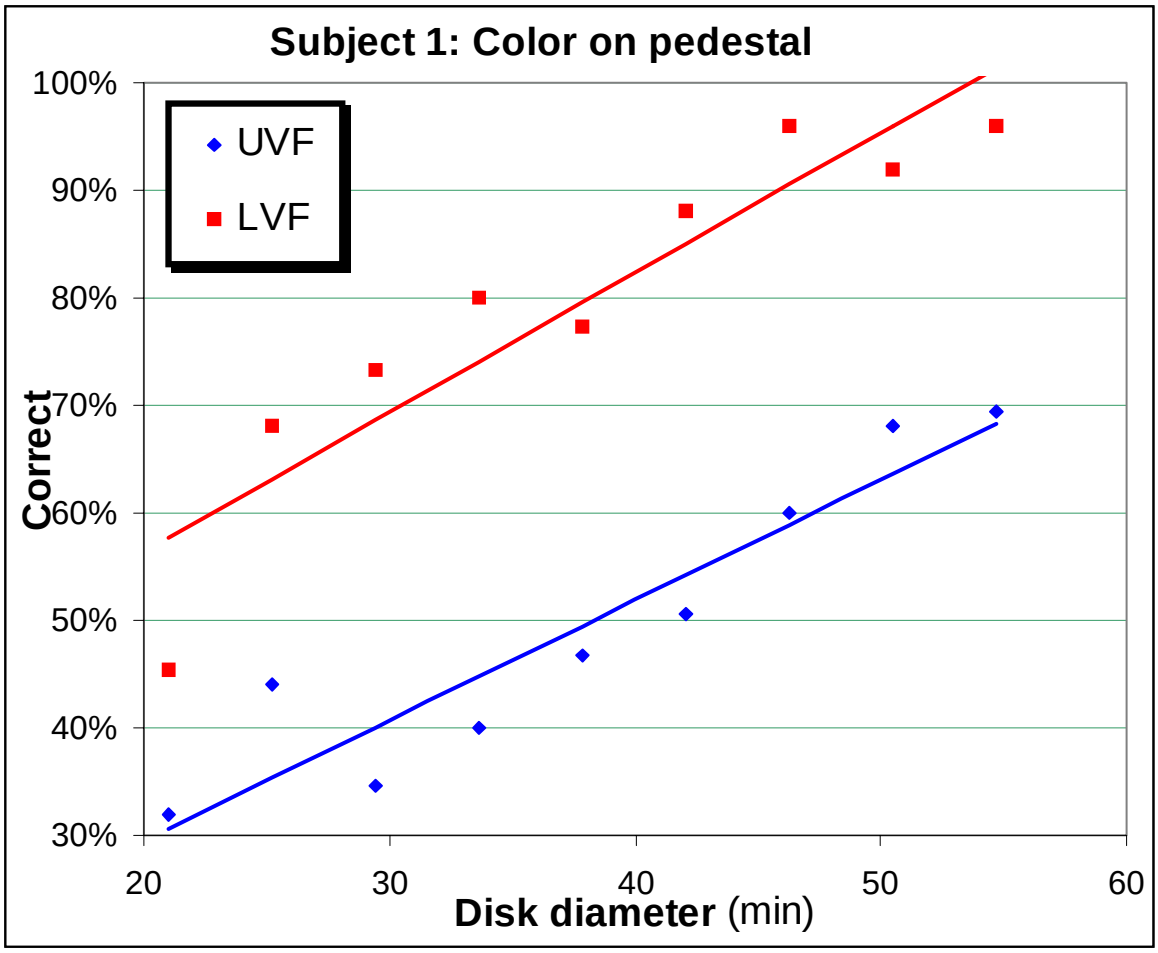


Fig. 7: Performance on color discriminations in UVF *versus* LVF as a function of saturation.

(Lines are regression fits)

Performance improved in both fields as the saturation of the target disks increased, but the slope is greater for the LVF. (As red increased, green was correspondingly decreased; at 0.60 ft-Cd/cm^2, target disks would be identical to distracters – pure pedestal blue). Note that the functions are also linear when expressed in *z*-scores (smaller graph).



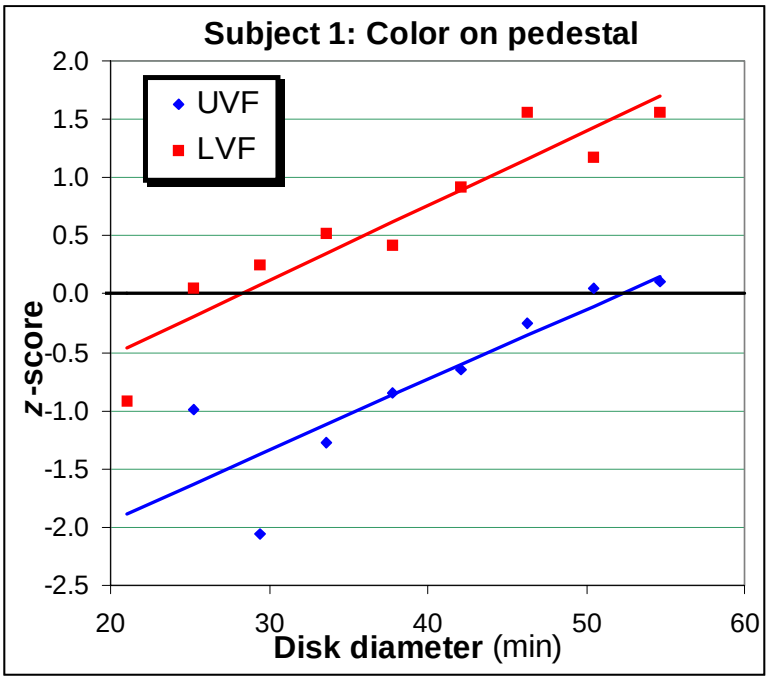


Fig. 8: Performance on color discrimination in UVF *versus* LVF as a function of disk size.

Performance improved in parallel in both fields as the size of the disks (fraction of area covered) increased. Performance was always better in the LVF.

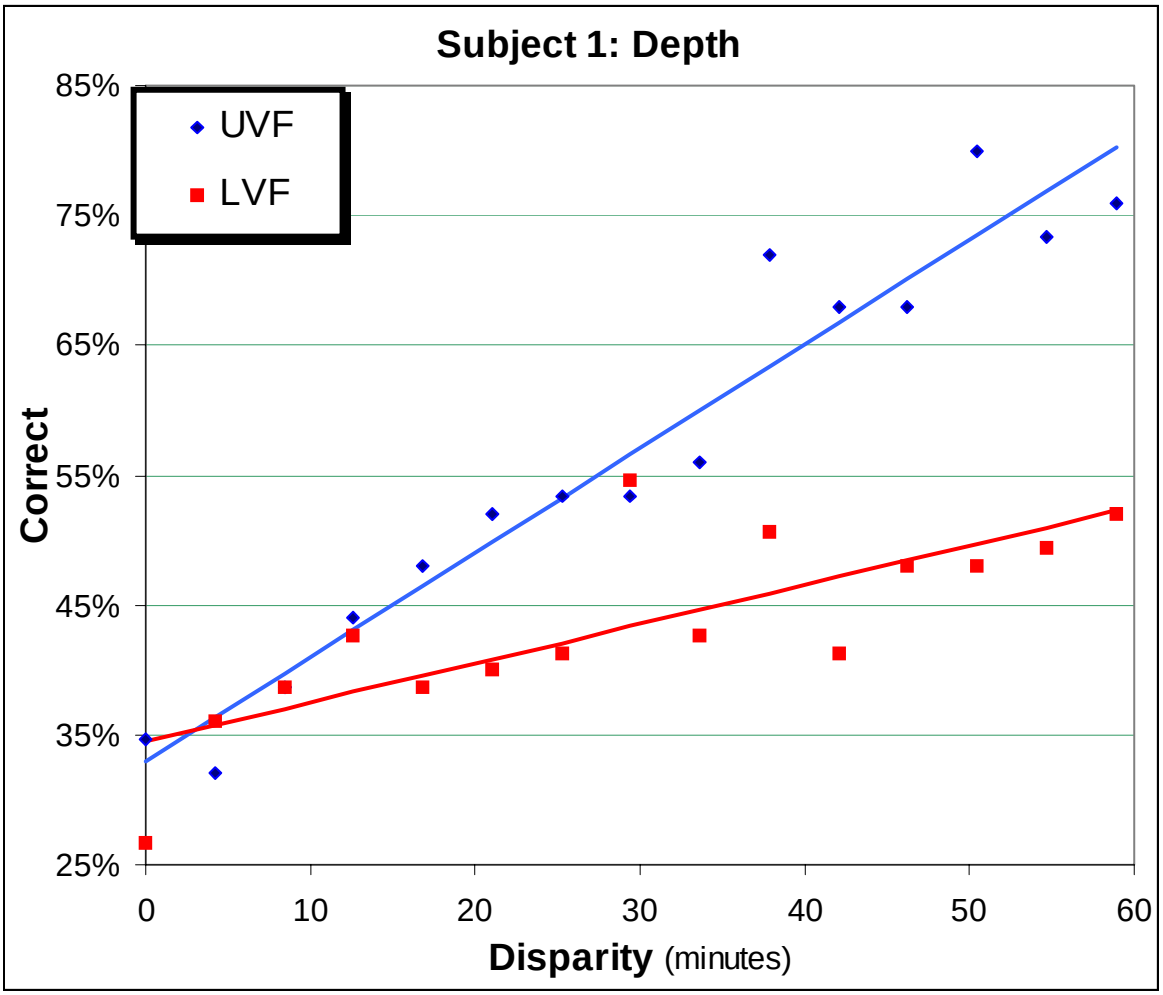
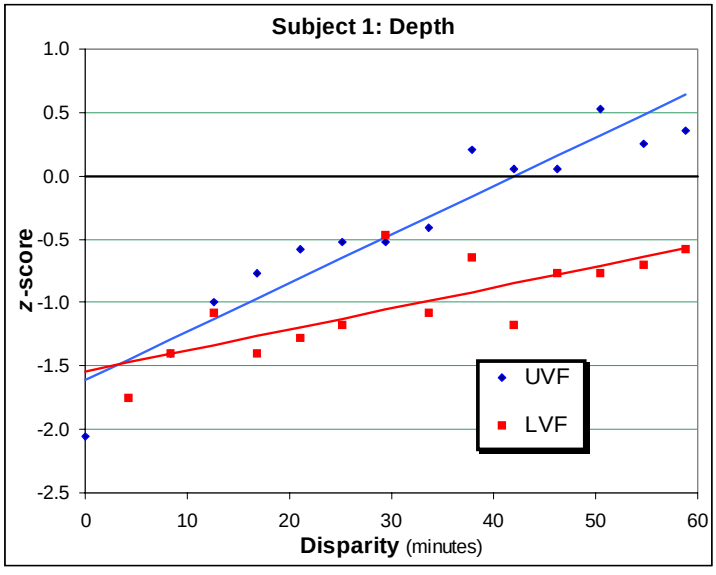


Fig. 9: Performance on depth discrimination in UVF *versus* LVF as a function of disparity between eyes. Target always appeared nearer than distracters.



Performance improved in both fields as the disparity of the target disks increased, but the slope was greater for the UVF.

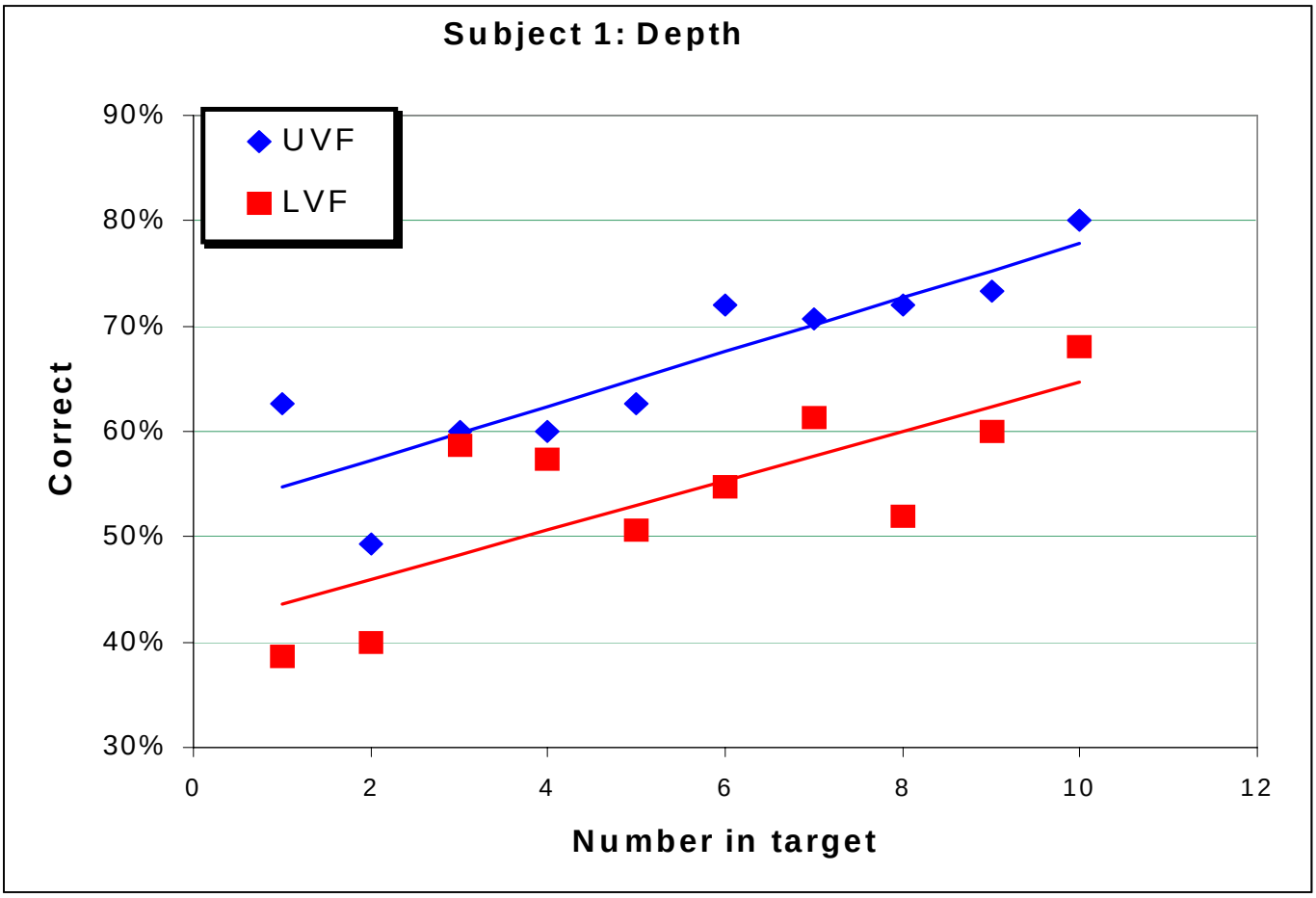
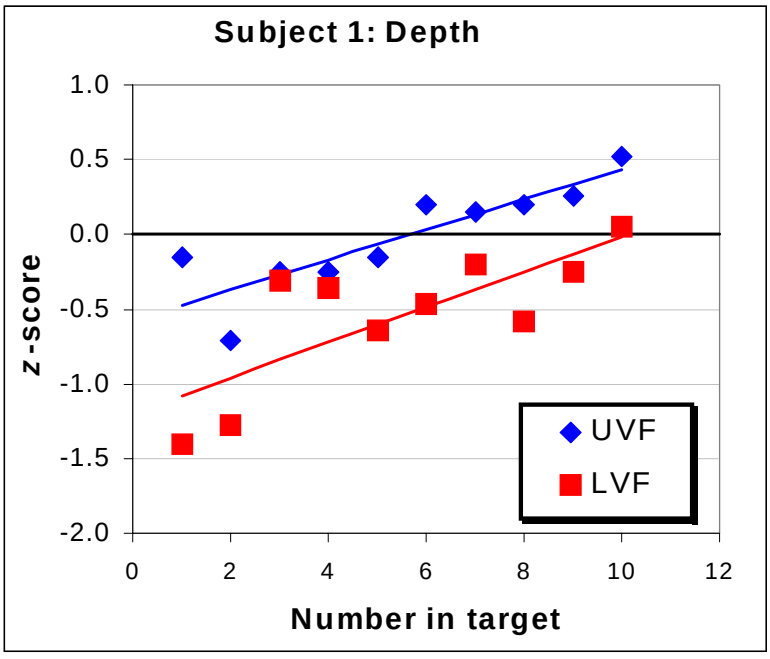


Fig. 10: Performance on depth discrimination in UVF *versus* LVF as a function of number of disks in target (disk density).

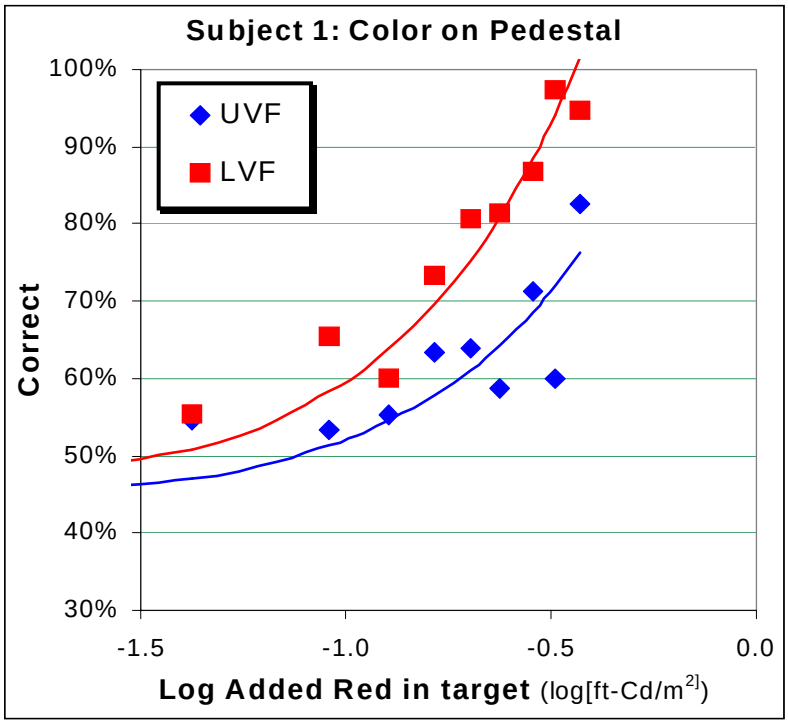


Performance improved in parallel in both fields as the number (density) of the disks increased. Performance was always better in the UVF.

Difficulty is not the key

- When difficulty was changed by variation along the dimension to be discriminated, the psychometric curve for the "better" performing field rose more steeply – consistent with greater sensitivity in the better field (Figs. 7 & 9). Note the log version of Fig. 7 (inset below). (Both curves would necessarily reconverge at 100% if the task were made easier).

- When difficulty was changed by an orthogonal variable, there was a constant advantage for the one field (Figs. 8 & 10).



Conclusions

- LVF superiority is found for tasks that preferentially engage the parvocellular system (e.g.: color, brightness).
- UVF superiority can be obtained by comparable tasks that engage the magnocellular system (e.g.: depth).
- Attention is apparently not a key factor; the field showing better preformance is simply more sensitive to the relevant dimension. When difficulty increases because of an orthogonal parameter, the difference remains essentially constant.