SPATIAL LOCATION AND HYPERACUITY: THE CENTRE/SURROUND LOCALIZATION CONTRIBUTION FUNCTION HAS TWO SUBSTRATES

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Abstract—Vernier acuity and jump detection were investigated using a perturbation technique, in which a flanking line is placed to one side of the target line. The size and direction of vernier displacement, or jump, required for no apparent change of location is strongly influenced by the separation between the flanking line and the test line and by its polarity. For flanks within a zone extending approximately 3'–4' to either side of the target line, the target's location is assigned to a weighted centroid of the complete luminance distribution: The target is pulled towards the flank, when the flank has a positive contrast polarity, and repelled when the polarity is negative. The effects of a dark flank on one side and a bright flank on the other are additive. Outside this central zone repulsion effects are obtained independent of the contrast polarity of the flank and flanks on opposite sides of the target line can cancel each other's influence. Varying the duration of the flank produces maximal effects in the surround with shorter duration than that required for maximal effects in the centre. Thus, while the localization contribution function resembles the popular difference of gaussians receptive field profile, it has two components reflecting differing mechanisms. In the centre the earlier centroid hypothesis can be applied with the addition of distance dependent weights. The surround has characteristics resembling the feature interaction seen in figural after-effects.

INTRODUCTION

The human visual system is extremely good at determining changes in the relative position of objects in space (Volkmann, 1863; Wülffing, 1892; Westheimer and McKee, 1977b) and yet it is known that the presence of a second feature may change the apparent position of the first (Köhler and Wallach, 1944; Watt et al., 1983). One may then ask, how does the spatial distribution of light contribute to the relative location of a feature?

Hyperacuity tasks [i.e. those that produce thresholds smaller than the diameter of one foveal cone (Westheimer, 1975)] provide a sensitive tool to address this question. Westheimer and McKee (1977b) presented data suggesting that the visual system utilizes the luminance distribution within a restricted region of about 2–3' of arc, and assigns the location of the object to that of the centroid (its centre of gravity). The exact weighting given to light at various distances was not determined but their data suggested only positive weights in the function. Watt et al. (1983) argued that if localization involved the determination of the centroid then the addition of an extra line in the target (within the relevant region) would move the centroid and thus change performance. They confirmed the change in performance and also found that the magnitude of the effect depended on the brightness of the added line as would be expected. Thus a luminance contribution function with positive weights for localization is supported in hyperacuity tasks.

Prior to these hyperacuity studies, Köhler and Wallach (1944) had also examined the influence of one stimulus feature on the apparent location of another, using figural after-effects. They found that features repel each other. Ganz (1966) formulated a model, based on lateral inhibition, to account for these and subsequent data (e.g. Pollack, 1958; Ganz, 1964). Ganz's model only predicts repulsion, that is, it assumes a luminance contribution function which only includes negative weights. Ganz was trying to explain a class of experiments in which the observer's task was to set two features to alignment (after prolonged inspection of an inducing stimulus), unlike the hyperacuity experiments which determine the threshold for misalignment. Interestingly the repulsion effects are not seen when the inducing and test stimuli are abutting, but require a small separation (Köhler and Wallach, 1944; Ganz, 1966).

Finally Ganz (1964) and Ganz and Day (1965) have reported attraction in figural after-effects for separations between the inducing and test stimuli smaller than about 3 min of arc and repulsion for larger separations. The repulsion effects have not been observed in hyperacuity tasks. In the experi
ments to be reported here we measure both the threshold for a detectable displacement and the position of the test line which gives a percept of "no difference" in an attempt to determine the luminance contribution function for spatial localization in hyperacuity tasks.

**METHOD**

The observer viewed from a distance of 6.8 m an oscilloscope with P31 phosphor that was driven by a PDP 11 minicomputer, in an illuminated room. The screen luminance, with no pattern displayed, was 8.0 cd/m². During an experiment target lines less than half a minute of arc in width were presented on a continuous background in the centre of the screen and a trial occurred every six seconds (unless otherwise specified).

In a trial, a target line 10 min of arc high was presented on the bright (95 cd/m²) background (38 min wide x 10 min high). After 500 msec the line was instantaneously displaced 0, 12, 24, or 36 sec of arc to either the left or the right and remained in that position for another 500 msec. The direction and the size of the jump were randomly chosen on each trial. At the instant of the jump a flanking line (10 min high) was presented parallel to the test line and at one of the following distances to the left or the right of the shifted target line: 72°, 144°, 216°, 288°, 360°, 432° or 504°. (The distance between the test line and the flank was held constant within each condition to ensure that no cue to the size or direction of the shift of the line could be obtained from a change in the height of the peaks or the troughs of the luminance profile.). After each stimulus presentation the observer specified whether the jump was to the left or the right. No feedback was given and observation was always binocular with natural pupils.

On each trial the flank was introduced randomly at the right or the left of the test line. During any session, both conditions occurred an equal number of times. Statistical analysis did not show differences due to the side of flank presentation. It was therefore possible to use half the difference between the means (50% correct points) of the two conditions as the measure of the shift in apparent position of the test line that is associated with the introduction of the flank, and this shift is independent of any response biases in either direction.

Most runs contained four flanking distances, each with flanks on the right or the left; thus eight possible flank positions were shown in random order within each session. Session orders were counterbalanced to factor out possible order effects.

In a complete experiment the observers made 300 responses in each condition. Psychometric curves relating the proportion of responses to the right against the direction and size of the jump were calculated. These curves were analysed by the methods of probits (Finney, 1952). Two statistics were extracted: The mean value which indicates the jump required to produce 50% correct detection; i.e. a percept of no jump (with no flanks this is usually zero) and a threshold value indicating the size of the jump required to produce a 25% change in performance from the 50% point. This latter value is a measure of the slope of the psychometric function. The method of probits also provides estimates of the standard errors for these two values. To arrive at the standard error estimates of the average mean-shift values reported in the Results section, we calculated half the square root of the sum of the squared standard errors of the two component means, right and left.

Four observers were employed in this study, all were highly experienced in psychophysical tasks, male, and had normal or corrected-to-normal vision. Their participation in particular experiments depended on time scheduling only.

<table>
<thead>
<tr>
<th>Experiment No.</th>
<th>Type</th>
<th>Flank contrast</th>
<th>Zone</th>
<th>M.G.</th>
<th>Threshold ± standard error</th>
<th>R.Y.</th>
<th>D.B.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Jump</td>
<td>Positive</td>
<td>Both</td>
<td>9.57 ± 0.27</td>
<td>15.6 ± 0.83</td>
<td>9.05 ± 0.28</td>
<td>10.76 ± 0.31</td>
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<tr>
<td>2</td>
<td>Vernier</td>
<td>Positive</td>
<td>Both</td>
<td>7.66 ± 0.43</td>
<td>7.25 ± 0.18</td>
<td>6.45 ± 0.16</td>
<td>7.21 ± 0.25</td>
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<tr>
<td>3</td>
<td>Jump</td>
<td>Negative</td>
<td>Both</td>
<td>9.30 ± 0.37</td>
<td>12.74 ± 0.41</td>
<td>7.97 ± 0.33</td>
<td>10.42 ± 0.35</td>
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<tr>
<td>4</td>
<td>Jump</td>
<td>Positive</td>
<td>Both</td>
<td>10.81 ± 0.24</td>
<td>8.52 ± 0.19</td>
<td>9.89 ± 0.24</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Vernier</td>
<td>Positive</td>
<td>Centre</td>
<td>6.65 ± 0.14</td>
<td>8.04 ± 0.01</td>
<td>8.29 ± 0.25</td>
<td></td>
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<tr>
<td>6</td>
<td>Jump</td>
<td>Positive</td>
<td>Centre</td>
<td>8.75 ± 0.31</td>
<td>10.59 ± 0.37</td>
<td>8.77 ± 0.22</td>
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</table>

All thresholds represent the average of values obtained with the flanks on either side. The values are averaged over a range of separations unless otherwise noted. Neither the side of presentation of the flank nor the separation between the flank and the test line significantly influenced the threshold.
Table 2. Individual thresholds for each flank separation and side, for the four observers. The data correspond to the conditions plotted in Fig. 1, which provides the mean shifts. Flank separation did not significantly influence the threshold.

<table>
<thead>
<tr>
<th>Flank Target-to-flank separation</th>
<th>72°</th>
<th>144°</th>
<th>216°</th>
<th>288°</th>
<th>360°</th>
<th>432°</th>
<th>504°</th>
<th>Mean</th>
</tr>
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<td>Observer contrast</td>
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<td></td>
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<td>M.G.</td>
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<td></td>
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<tr>
<td>Positive</td>
<td>8.07</td>
<td>10.22</td>
<td>10.31</td>
<td>7.68</td>
<td>9.6</td>
<td>9.65</td>
<td></td>
<td></td>
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<tr>
<td>Negative</td>
<td>9.54</td>
<td>9.81</td>
<td>9.23</td>
<td>10.39</td>
<td>10.94</td>
<td>8.23</td>
<td>11.07</td>
<td>9.57</td>
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<td>E.S.</td>
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<td></td>
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<tr>
<td>Positive</td>
<td>13.83</td>
<td>15.79</td>
<td>15.65</td>
<td>15.15</td>
<td>13.74</td>
<td>16.73</td>
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<tr>
<td>R.Y.</td>
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<td></td>
<td></td>
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<td></td>
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<td>Positive</td>
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<td>14.05</td>
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<td>12.74</td>
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<td>D.B.</td>
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<td></td>
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<td>8.77</td>
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<td>Negative</td>
<td>8.39</td>
<td>7.48</td>
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<td>Mean</td>
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<tr>
<td>Target-to-flank separation</td>
<td>8.72</td>
<td>8.47</td>
<td>8.21</td>
<td>8.87</td>
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<td>14.05</td>
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<td>432°</td>
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<td>7.61</td>
<td>9.15</td>
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<td>504°</td>
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<td>8.77</td>
<td>7.68</td>
<td>7.54</td>
<td>8.03</td>
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<tr>
<td>Mean</td>
<td>8.39</td>
<td>7.48</td>
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<td>6.79</td>
<td>11.66</td>
<td>8.28</td>
<td>7.97</td>
</tr>
</tbody>
</table>

RESULTS

Experiment 1. Jump experiment: positive flank contrast

In the first experiment, sensitivity to a jump was measured as a function of the separation between the target line and the flanking line. Both lines had the same contrast polarity although the flank had only 25% of the intensity of the target line. The target line alone had an intensity of 0.775 cd/m.

The thresholds, summed across flank distances, are presented in Table 1. The magnitude of the distance between the target line and the flank did not significantly affect the threshold [F (6,49) = 0.25, P > 0.05]. The thresholds for each separation are presented in Table 2.

The presence of the flank did, however, influence the mean value in each condition, that is, the flank’s presence in effect caused the apparent position of the target line to change. The size and direction of the shift is plotted as a function of flank separation for each individual observer in Fig. 1 (solid lines). These curves will be referred to as mean-shift functions from here on.

The implication of this curve is that, when the flank is close, the target’s position is pulled towards the flank. This behaviour is consistent across all four observers. The pattern of results cannot be com-

Fig. 1. The induced shift of the mean location of the target line, after a jump accompanied by the introduction of a flanking line, is plotted as a function of the separation between the target and the flanking line for four observers. The positive contrast target line was presented with a flank of either positive (solid lines) or negative (dashed lines) contrast. The average standard error did not vary systematically as a function of separation and was 1.13 (1 SE = 0.03) sec of arc.
pletely described by a centroid hypothesis including only positive weights, as this does not predict the surround repulsion zone, but the results are closely modelled by the popular Difference-of-Gaussians (DOG) functions. (The return to near-zero shift at larger distances implied by this model was not observed here. A supplementary experiment demonstrated quite large repulsion effects even with a separation of 16.8°. We did not pursue the outer limits to this effect.) It is important to note, however, that our empirical curves indicate a property of position coding mechanisms, whatever basis they may have in luminance-coding mechanisms.

Experiment 2. Vernier acuity

Before elaborating on the data from Experiment 1 it would be useful to know if the results reflect a specific property of the jump detection task or if they reflect a more general property of location-coding mechanisms in the visual system. A vernier acuity experiment was run to examine this issue. In this experiment the upper and the lower test lines and the flank were all presented simultaneously for 500 msec. The observers viewed the same screen as before but the background patch was 15 min high x 34.2 min wide and had a luminance of 37.4 cd/m². The vertical vernier stimulus was composed of two 6 min high lines separated by a 3 min gap. The location of the top line was varied and the flank was placed beside the fixed lower line. This ensures that in each condition the separation between the flank and the lower line is always constant. The flank was also 6 min high and line intensities were as in Experiment 1.

A 500 msec trial was presented every three seconds and the observer's task was to indicate whether the top line was to the right or the left of the bottom vernier line. All other details were as in the previous experiment.

The thresholds for vernier acuity, averaged across flank-to-target separations, are lower than for jump detection and are presented in Table I. The effect of flank separation was not significant [F (6,49) = 1.11, P > 0.05].

The flank did have a substantial effect on the mean location (50% correct point) of the target line, however. The mean-shift curves for each observer are plotted in Fig. 2.

At small separations the target line is pulled towards the flank but at larger separations a clear repulsion of the target line is produced. Thus, in spite of the variation in display parameters the effects of the flanking line are the same in the jump and the vernier experiments. The repulsion generated by a feature in the surround zone is clearly a robust characteristic of the mechanisms that code spatial location.

Experiment 3. Jump Experiment: negative contrast flank

As discussed above, the mean-shift function resembles a DOG receptive field which indicates the magnitude and polarity of the effect of a fixed amount of light as a function of its location on the
field. However, in these experiments we are measuring location not luminance detection thresholds and the assumption that the two are linked must be tested.

On the simple interpretation of shared mechanisms, one might expect a reversal of polarity of the weighting function on reversal of the polarity of the flank, much as was found in the sensitization experiments of Westheimer and Wiley (1970). Consequently an experiment was designed in which the flank was seen as a dark line against a uniform background, although the test line remained bright. In all other respects this experiment is the same as Experiment 1. The dark flank was 10 min high and subtracted as much light form the background as was added by the bright flank in Experiments 1 and 2.

As before, the separation between the target and the flanking lines did not influence the thresholds \[F(6,49) = 0.03, P > 0.05\]. The thresholds, averaged across separations, are given in Table 1. As before, flank separation had a significant influence on the mean. The mean-shift function is plotted in Fig. 1 as dashed lines for each observer. It is clear that the profile does not simply invert, however. At small flank separations the dark flank has an effect in the opposite direction than the bright flank, but there is no such reversal at larger distances.

Thus, while the data from Experiment 1 were reminiscent of a DOG receptive field profile they do not, in fact, reflect the operation of simple luminance weighting functions. One explanation is that the central zone (2–3 min of arc on either side of the target line) does generate an approximation to a centroid of the luminance distribution but the surround zone can only generate a repulsion effect and is therefore not a simple luminance interaction phenomenon. The effect obtained could be caused by rectification in the surround or by feature rather than luminance interactions.

**Experiment 4. Jump with two flanks**

The experiments presented above have shown that when flanks are close to a target line, it is pulled towards the flank for a positive flank contrast but they push each other apart if the flank has a negative contrast. A flank in the surround region always causes repulsion under the conditions presented. The next experiment employs two flanking lines of opposite contrast polarity, one to either side of the target line. Line and background luminances were as used in the previous jump experiments. The flanks appeared at the time of the jump and the separation between the target and the flanks was independent of the size and direction of the jump. The observer’s task was simply to detect the direction of the jump.

The same flank-to-target separations were employed as in the previous experiments and the flanks were placed symmetrically about the target line. Two conditions were run for each separation, with the contrast polarity of the flanks reversed across conditions.

The results of the previous experiments lead to the following expectations: When the two flanks are at small separations and within the zone that is influenced by contrast polarity, the target should be attracted towards the bright flank and away from the dark flank thereby enhancing the mean shift. At larger separations, where both contrast polarities produce a repulsion of the target line there should be little, if any, shift of the mean.

The thresholds, averaged across all conditions are presented in Table 1. Flank separation did not have a significant effect on the threshold \[F(6.35) = 0.69, P > 0.05\].

The effect of the flanks on the mean location of the target line is plotted as a function of target-to-flank separation in Fig. 3 for the three observers. In this figure “attraction” indicates that the target line was pulled towards the positive contrast flank. The results, indicated by the data points, are as expected. Within the central zone the target line is strongly pulled towards the bright flank whereas in the surround zone the effect of the two opposite contrast flanks cancel each other. Predictions were generated by taking the difference between the results of Experiments 1 and 3 which indicates the expected shift of the target line if the effects of the flanks are additive. The dashed lines in Fig. 3 indicate \(\pm 2\)SE of the predictions and show quite good agreement with the data obtained in the current experiment.

**Two mechanisms?**

The experiments already presented have suggested that a small region of space centred on the target line and extending 2–3° to either side is treated as a single unit by the visual system (see also Westheimer and McKee, 1977a). Within this region the visual system appears to use the centroid as the location of a feature (see also Fendick, 1984; Watt et al., 1983; Watt and Morgan, 1983). The weight given to a unit of light as a function of distance from the target line will be discussed below.

Outside this zone there is a region in which features repel each other. The results of Experiments 1 and 3 indicate that this surround zone does not simply add luminance with negative weight in the calculation of the centroid. This region acts like a rectifier in producing the same direction of effect for both positive and negative contrast flanks.

**Experiments varying flank durations.** The next two experiments will determine the relative size of the flank’s effect on the target line as a function of the flank duration.

**Experiment 5. Vernier acuity**

The procedural and display characteristics were the same as for Experiment 2 except that the duration of the vernier lines was reduced to 80 msec and the flank was either 20, 40, 60 or 80 msec in duration. The flank appeared at stimulus onset and was randomly presented to either side, at either 72° or 288° of arc.
Fig. 3. The shift induced in a positive contrast target line, in a jump experiment, when a positive contrast flank is presented to one side and a negative contrast flank to the other. The induced shift in the direction of the positive contrast flank is plotted as a function of target-to-flank separation for three observers (solid symbols) with ±1 SE indicated. The dashed lines indicate ±2 SEs of the shift predicted if the effects of a bright flank on one side and a dark flank on the other are additive. These lines were generated for each observer from the data in Fig. 1. Note that the scale on the ordinate is different to that in Figs 1 and 2.

separation. The first of these is clearly within the central zone while the latter is in the surround. In each condition a single flank was shown. The observer’s task was simply to say whether the top vernier line was to the right or the left of the lower one.

The flank’s duration had no effect on the threshold at either 72° [F(3, 8) = 0.26, P > 0.05] or 288° [F(3, 8) = 0.57, P > 0.05]. The observer’s thresholds for the 72° and 288° separations are presented in Table 1.

The effect of flank duration on the mean is plotted for the three observers in Fig. 4. Since the magnitude of the maximum mean shift is different in the centre and surround, the data have been normalized by dividing the value obtained at each duration by the size of the shift obtained with an 80 msec flank duration (i.e. the condition in which the flank and the test durations are identical). The size of the average mean shift for each observer with the maximum flank duration is also written on Fig. 4 with 1 SE indicated in the parentheses. The data for all three observers indicates that the normalized magnitude of the mean shift is greater in the surround than in the centre at shorter durations.

Experiment 6. Jump experiment

A jump experiment was run to verify that the results of the previous experiment were a feature of more general mechanisms of spatial localization and not just of the vernier acuity task. The display characteristics and experimental details were the same as in Experiment 1 with the single exception that the bright flank was varied in duration. The flank appeared at the time of the jump, as before. The central flank was at 72° separation while the surround was at 288° for observers M.G. and R.Y. and at 360° for observer E.S.

The average thresholds for the three observers for both flank separations are presented in Table 1. No consistent effect of flank duration on the threshold was found and the differences between conditions

![Fig. 4. The magnitude of the induced mean shift is plotted as a function of flank duration. The target line’s duration was 80 msec and the shift induced by an 80 msec, simultaneously presented, flank is indicated on the right hand side of the figure. The results are expressed as a proportion of the induced shift obtained with the maximum flank duration in both the centre (solid lines) and the surround (dashed lines) when the three observers are performing a vernier task.](image-url)
Spatial location and hyperacuity

The magnitude of the induced mean shift is plotted as a function of flank duration for three observers. The target line’s duration was 500 msec and the shift induced by a 500 msec flank, presented at the same time as the jumping line reaches its second position, is indicated on the right hand side of the figure. The results are expressed as a proportion of the induced shift obtained with the maximum flank duration in both the centre (solid lines) and the surround (dashed lines).

with different separations were not significant for any observer.

The effect of the flank’s duration on the mean is plotted for three observers in Fig. 5.

The results have been normalized in the same manner as for the previous experiment. The data for all three observers replicate the findings of Experiment 5 in all major respects. With small separations the test line is pulled towards the flank and the magnitude of this effect increases with flank duration. At larger separations the target line is pushed away from the flank. This latter effect is maximal (a value near 1.0 in Fig. 5) with short flank durations. The magnitude of the surround effect is consistently a greater proportion of the effect obtained with the maximum flank duration than the central effect at short flank durations. The amount of attraction or repulsion with the maximum flank duration is marked on Fig. 5 and was always more than one standard error away from zero.

Variation of the duration of the flank has, once again, demonstrated that the centre and surround zones of the spatial localization function have different characteristics. The magnitude of the mean shift increased approximately linearly in the centre as flank duration (and integrated energy) increased while in the surround the magnitude of the mean shift shows an initial rapid rise and then only a small change with duration.

DISCUSSION

The experiments reported here were designed to investigate the mechanisms underlying visual spatial localization. A perturbation technique was employed in which the location of a target line was judged relative to a comparison line presented either simultaneously (Vernier experiments) or successively (Jump experiments) and the positions at which both lines were assigned the same location (50% responses in either direction or mean location) were ascertained.

The means were significantly influenced by the separation between the target and an adjacent flanking line in every experiment. When this distance was small (less than 3–4°) and the flank had a positive contrast, the test line was measured to have a mean location closer to the flank than its veridical position. Larger separations produced an estimate of the mean that was further away from the flank than the target line’s true location.

The experiments also demonstrated, by varying either the contrast polarity or the duration of the flank, that the central and surround zone are the effects of different underlying substrates.

The central zone

Westheimer and McKee (1977a) proposed that within a limited region of space (2–3°) the visual system uses the entire luminance profile and assigns the location of a feature to the centroid or first moment of the distribution. Watt et al. (1983) provided some support for the model but neither study systematically varied the separation between features.

The present investigation, undertaken to test the limits within which the centroid concept can be applied, has yielded data on the localization shift due to nearby features. The data are not compatible with a formulation which gives a feature equal weight as it is removed from the test line, but they can be reconciled with the centroid view by hypothesizing weighting factors that are a function of distance. In this way the centroid hypothesis can be stated in the form

\[ \bar{x} = \sum I_x w_x / \sum I_x w_x \]  

where \( \bar{x} \) is the induced shift in the centroid that was measured, \( x \) is the distance between target and flanking lines, \( w_x \) is the weight at distance \( x \) and \( I_x \) is the intensity at \( x \). Using this formula and the data from Figs 1 (solid lines) and 2 a weighting function has been calculated (see Fig. 6).

It has been constructed on the basis of data from perturbation experiments and extends the previous formulation in two ways,

(1) except near the very centre, weights are never 1, so that outlying light components do not contribute to the localization as effectively as inner ones.

(2) for a perturbing feature with positive contrast, there is a surround zone in which the weights are negative.
energy of the target line is constant, the effect of a flank increases monotonically as flank duration (and energy) increases. The precise limits of temporal integration have not been addressed in this study.

The surround zone

The current data indicate that the introduction of the additional line at a separation greater than 3-4' produces a repulsion of the mean location of the target line. The repulsion is found independent of the contrast polarity of the flanking lines indicating that it is not simply a byproduct of receptive fields with luminance weighting functions that contain an inhibitory surround (Westheimer, 1967; Kulikowski and King-Smith, 1973; Hines, 1976; Rentschler and Hilz, 1976; Limb and Rubinstein, 1977; Wilson, 1978). Indeed the effect of a bright flank on one side can be cancelled by a dark flank on the other. Within the central zone this procedure produces a substantial shift of the mean of a positive contrast target line towards the positive contrast flank. The surround also differs from the centre in not being greatly influenced by variation in the flank's duration. Repulsion is maximal with short durations (in comparison to those required for the maximum effect in the centre) suggesting that once a flank is detected it may have the full effect.

The zone of repulsion has not been consistently demonstrated in the hyperacuity literature. One study did, however, look for such an effect. Rentschler et al. (1975) had observers adjust two lights until they were directly above (and below) a test line under conditions in which the distance to an inducing line was varied. One observer showed a weak surround effect while the other did not.

We have consistently shown the surround in several observers in six experiments using two-alternative forced-choice methodology. Differences in the magnitude of the effect between individuals do exist but in all cases significant repulsion was obtained. It may be very important to interleave trials with the flank on opposite sides and to derive an average mean shift in order to eliminate response biases before the effect can be reliably observed.

Previous evidence suggesting a surround zone

Several earlier studies examining figural aftereffects suggest that a surround zone should be present. In a series of experiments Köhler and Wallach (1944) demonstrated that prolonged inspection of an inducing figure causes an apparent displacement of a spatially adjacent (although not abutting) subsequently presented target away from the inducing figure. They did not report an attraction effect with small separations but, since eye movements were not controlled precisely, the fixation accuracy required to demonstrate the small zone in which attraction is obtained may not have been present. The use of simultaneous presentations here avoided this problem. The results of Köhler and Wallach have been replicated many times (see Robinson, 1972 for a review). The most interesting replication for the
present purposes is that of Ganz and Day (1965) who found both attraction and repulsion effects with the changeover occurring at about 3-4' of separation. Consistent with the idea that attraction is due to a luminance weighting function in which weights decrease with increasing distance, they found that attraction was obtained with a larger range of separations when the luminance of the inducing figure was higher.

The amount of repulsion obtained also increases as luminance contrast increases (Pollack, 1958) although contrast polarity is not an important factor (Ganz, 1964) as was found in the current study employing hyperacuity tasks. Indeed, repulsion can be obtained when only chromatic (and not luminance) contrast defines the feature (Day, 1959).

Finally both Köhler and Wallach (1944) and Ganz and Day (1965) have demonstrated that repulsion can be obtained using dichoptic presentation while the latter failed to find interocular transfer for the attraction effect. These results suggest that attraction seems to reflect properties of the monocular pathways while repulsion involves at least some binocular components. The attraction may, however, also involve binocular components since it is hard to be sure that fixation was controlled precisely enough to demonstrate the small central zone.

The parallels between the figural after-effect literature and the data presented here are interesting. Further they suggest some experiments that could be performed to examine the locus within the visual system of attraction and repulsion effects in hyperacuity tasks. The literature supports our conclusion that attraction and repulsion are the results of two separate underlying mechanisms, one concerned with the luminance distribution within a restricted region and the other reflecting interactions between features.

While the parallels with the previous literature are strong those parallels only apply to the variation in the mean location. The current data show that in spite of this change in mean our sensitivity to a change in location from that position is not altered by these manipulations. The importance of measuring both the mean and the threshold in the analysis of hyperacuity mechanisms cannot be stressed too greatly. Any measure that only determines a single point on the psychometric function will have a value reflecting the combined effects of mean shift and threshold changes with no way of separating the two. The current data show this separation to be very important.

It remains necessary to characterise fully the mechanisms underlying the two zones in the spatial contribution function for localization but several things are now clear:

(1) at least two mechanisms are involved in determining a line's apparent location,
(2) the sensitivity of the visual system to a change in location (i.e. hyperacuity) is to some extent independent of both of these mechanisms.

(3) simple descriptions of the luminance distribution will not allow easy prediction of the apparent location of features within an image.

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