Vision Res. Vol. 29, No. 10, pp. 1463–1469, 1989
Printed in Great Britain.

0042-6989/89 $3.00 + 0.00

BOTH SEPARATION AND ECCENTRICITY CAN LIMIT PRECISE POSITION JUDGEMENTS: A REPLY TO MORGAN AND WATT

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(*Received* 24 *February* 1989)

Abstract—Weber's law is ubiquitous in position judgements. In a variety of position acuity tasks, the position threshold is proportional to the separation of the reference features. Recently, we (Klein & Levi, 1987; Levi, Klein & Yap, 1988) suggested that two sensory processes may serve to limit position acuity, and thus contribute to Weber's law for position. One is the target separation, and the other is the target eccentricity. In order to test this idea, we pitted separation against eccentricity by measuring spatial interval discrimination thresholds on an iso-eccentric arc (Levi et al., 1988). Over a 5-fold range of separations, we found that thresholds were independent of separation, and concluded that at large separations, eccentricity can limit precise position judgements. In the preceding article, Morgan and Watt (1989) have questioned this conclusion, and have shown that the effects of eccentricity are small in an arc length discrimination task. In the present article, we: (i) address the objections raised by Morgan and Watt; (ii) show that our data and 2-mechanism model are consistent with many previous studies; and (iii) show that Morgan and Watt's task is inherently difficult, so that rather than tapping the sensory limits imposed by the target eccentricity, performance on the arc length task is constrained by the cognitive demands of the task, or by the difficulty of reconstruction. In contrast, the measurement of chord length (spatial interval discrimination on an iso-eccentric arc) can be simply done by calculating the distance between the endpoints. Thus, at large separations, thresholds for the chord length judgements are much lower than those of Morgan and Watt, and are proportional to the eccentricity of the targets.

Weber's law   Psychophysics   Periphery   Spatial interval   Position discrimination   Hyperacuity   Localization

INTRODUCTION

Weber's law is pervasive in sensory psychology. A good deal of evidence for Weber's law derives from studies of position judgements, where, over a wide range of conditions, the position threshold is approximately proportional to the separation of the reference features (Volkmann, 1858; Fechner, 1858; Klein & Levi, 1985, 1987; Andrews, Butcher & Buckley, 1973; Beck & Schwartz, 1979; Beck & Halloran, 1985; Westheimer & McKee, 1977; Andrews & Miller, 1978; Hirsch & Hylton, 1982; Yap, Levi & Klein, 1989; Levi & Klein, 1989a). As Morgan and Watt (1989) have pointed out, Weber's law is not well understood, thus, an understanding of the factors contributing to Weber's law is critical to our understanding of space and distance perception.

Recently, Klein and Levi (1987) suggested that at least *two* sensory factors may serve to limit positional acuity and thus contribute to Weber's law for position. One factor is the target separation, which is dominant when the separation is small with respect to the target eccentricity. The second is the eccentricity of the targets (Klein & Levi, 1987; Levi et al., 1988), which dominates when the separation is large with respect to the target eccentricity. We argued that the spatial grain of the retina and cortex varies linearly with eccentricity; thus the position of the features becomes increasingly uncertain as their separation, and hence their eccentricity increases. In order to test this idea, separation was pitted against eccentricity by measuring bisection thresholds for short lines presented on an iso-eccentric arc with a radius of 10 deg, so that the interline separation could be varied while holding the stimulus eccentricity constant (Levi et al., 1988). Over a range of separations from about 2 to 10 deg, we found that thresholds were more or less independent of separation (actually increasing rather than decreasing at the smallest separation), and concluded that eccentricity not separation is the critical limiting factor in precise position judgements over a range of large separations. This conclusion has been questioned by Morgan and

Watt (1989), on the basis that: (1) only a single eccentricity (10 deg) was tested, thus providing no direct evidence for the role of eccentricity; (2) our bisection paradigm places the middle "reference" target at an eccentricity off the iso-eccentric arc, and this may have cancelled out the effects of separation; (3) the surprising increase in the thresholds for the smallest separation (2 deg) might have been "a consequence of resolution failure in the periphery"; (4) we failed to consider previous work by Beck and Halloran (1985) who found only small and inconsistent effects of eccentricity in a two-dot orientation task; (5) Morgan and Watt (1989) presented new data on an arc length discrimination task in which the effects of eccentricity are claimed to be very small, in disagreement with our results.

The present letter addresses the objections raised by Morgan and Watt. We show that our results are largely consistent with many previous studies of the role of separation and eccentricity in distance judgements including those of Beck and Halloran (1985). Finally, we consider why our results may differ from those of Morgan and Watt (1989).

The role of eccentricity

Elsewhere (Levi & Klein, 1989a) we present extensive data using the iso-eccentric paradigm over a wide range of eccentricities. Specifically, we measured 2- and 3-line spatial interval and alignment thresholds on iso-eccentric arcs of different radii, from 0.675 to 10 deg in order to test a large range of separations and eccentricities. Our results, consistent with earlier work (Klein & Levi, 1987) suggest that there are at least *two* processes which limit position judgements: one is sensitive to separation, the other to eccentricity. If the angle subtended by the fixation point and the outside pair of iso-eccentric test lines is considered, then for both the 2- and 3-line spatial interval and alignment tasks, when the angle is less than approximately 40 deg, thresholds are proportional to separation, and when it is between 40 and 180 deg, thresholds are proportional to eccentricity. The lines in Fig. 1 illustrate schematically how these two processes constrain performance. If target eccentricity is a critical limiting factor in precise position judgements then the thresholds obtained on arcs of different radii should scale simply with eccentricity (Morgan & Watt, 1989). The abscissa in Fig. 1 represents the angle between the fixation point and the pair of

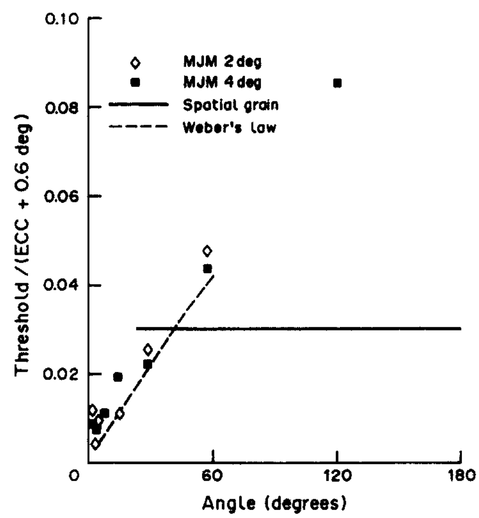

Fig. 1. Schematic showing the two putative mechanisms which constrain position judgements. The dashed line in Fig. 1 shows the "Weber's law" process, i.e. thresholds are proportional to separation (illustrated here is a Weber fraction of 0.05) and independent of eccentricity. The solid line shows the eccentricity or "spatial grain" process where thresholds are proportional to eccentricity and independent of separation (the solid line shows thresholds equal to 0.03 (E_{cc} + 0.6) degrees). The abscissa represents the angle between the fixation point, and the pair of iso-eccentric test lines. Plotting the angle has the effect of taking into account eccentricity, since the same angle necessitates larger separations as eccentricity increases. The ordinate is the position threshold specified as a fraction of E (the target eccentricity) + E_2 (0.6 deg). In several position tasks, over a range of eccentricities from 0.675 to 10 deg, we found that plotting the data on these axes resulted in a more or less unitary function (Levi & Klein, 1989a). At each eccentricity, for angles less than about 40 deg, thresholds were proportional to separation, while for angles larger than 40 deg, they were proportional to eccentricity. Our 2-line separation data is in quantitative agreement with the lines shown in Fig. 1. The data in Fig. 1 are re-plotted from Morgan and Watt (1989, Fig. 3). Specifically, we have replotted the iso-eccentric curve length data of observer MJM at eccentricities of 2 and 4 deg. Their data have been transformed in two ways: (1) rather than plotting the line-length values (their abscissa) we calculated the angle subtended between the endpoints of the lines and the fixation point, and have plotted these angle (separation) values on the abscissa; (2) Morgan and Watt specify their thresholds at $d' = 1.0$. Therefore we multiplied their threshold Weber fraction values by 0.675, and then divided the values by E_{cc} + 0.6 deg, in order to specify them as a fraction of "effective eccentricity". A comparison of their data with the two curves illustrated in Fig. 1 shows that at large separations their thresholds are about 2–4 times higher (worse) than our prediction, and are indeed consistent with an asymptotic Weber fraction of about 0.05–0.08. Morgan and Watt's poor performance at large angles (long curves) as shown in Fig. 1, indicates that their curve length discrimination task is inherently difficult since the observer cannot simply calculate the distance between the endpoints, but must calculate the total length of the arc.

iso-eccentric test lines. Plotting the angle has the effect of taking into account changes in scale with eccentricity, since the same angle necessitates larger separations as eccentricity increases, and is consistent with the results of our previous work (Levi & Klein, 1989a) which suggests that for several tasks (2- and 3-line spatial interval discrimination and 2- and 3-line alignment) the angle may provide an approximate scaling for eccentricity along the horizontal axis. Note that the angle provides only an approximate scaling because it does not take into account the nonzero X axis intercept, E_2 (see below). The exact formulation is given in Levi and Klein (1989a). The ordinate is the position threshold specified as a fraction of E (the target eccentricity) $+ E_2$ (0.6 deg). We chose the value 0.6 deg, because in a number of studies we have found that position thresholds (Th) vary with eccentricity (E) according to $Th = Th_f(E/E_2 + 1)$, where Th_f is the foveal threshold, and E_2 is between 0.4 and 0.9 deg. This is true for abutting Vernier acuity (Westheimer, 1982; Levi, Klein & Aitsebaomo, 1985), bisection (Yap, Levi & Klein, 1987a; Klein & Levi, 1987; Levi & Klein, 1989a) and 2-line interval discrimination (Yap et al., 1989; Levi & Klein, 1989b).

The solid line shows the eccentricity or "spatial grain" process where thresholds are proportional to eccentricity and independent of separation. The line shown is given by $Th = 0.03 \times (E + 0.6)$ deg, in agreement with our data for 2-line spatial interval judgements (Levi & Klein, 1989a). The precise fraction depends upon the task. In our previous study (Levi et al., 1988) we noted that for 3-line bisection, thresholds were approx. $0.02(E + 0.6)$ deg over a range of large separations ($\approx$2–10 deg). Even better (lower) thresholds are found for 3-line alignment (Klein & Levi, 1987; Levi & Klein, 1989a, and discussed further below).

The dashed line in Fig. 1, given by $Th = 0.05 \times$ separation, shows the "Weber's law" process, i.e. thresholds are proportional to separation (illustrated here is a Weber fraction of 0.05 in agreement with our 2-line data) and independent of eccentricity. Extension of the Weber line in Fig. 1 to large angles (separations), shows that there is a large difference in the sensitivity of these two putative mechanisms. By expressing the separation in terms of the angle, θ, (abscissa of Fig. 1) and eccentricity, E, we obtain the relationship, $Th = 0.1(E + 0)\sin(\theta)$. As discussed by Klein and Levi (1987), in the Weber's regime the value of E_2 is close to 0 deg whereas in the cortical grain regime the value of E_2 is about 0.6 deg. That is, in the Weber's regime at a ***fixed angle***, thresholds are proportional to E rather than $E + 0.6$ deg which was true for the spatial grain regime. In order to plot the dashed line on the same ordinate as the solid line we assumed an eccentricity of 3 deg so that the dashed line is given by $Th/(E + 0.6) = 0.1\, E/(E + 0.6) \sin(\theta) = 0.083 \sin(\theta)$ for $E = 3$ deg. This eccentricity was chosen because the data of Morgan and Watt (1989) that is also plotted in Fig. 1, and is discussed later, was taken at eccentricities of 2 and 4 deg.

We found (Levi & Klein, 1989a) that the effect of the transformation of the axes in Fig. 1 was to collapse the widely disparate data from the different eccentricities (about a 10 fold range in thresholds at large separations from 1.25 to 10 deg eccentricity) into a more or less unitary function, so that at each eccentricity, for angles less than about 40 deg, thresholds were proportional to separation (i.e. thresholds for the 2-line task followed the dotted line), while for angles larger than about 40 deg, they are proportional to eccentricity (i.e. thresholds were clustered around the solid line). In other words, our results suggest that over a large range of eccentricities, both separation and eccentricity can constrain position judgements, and that the data do scale with eccentricity.

The effect of a reference target off the iso-eccentric arc

Morgan and Watt raised a potentially serious methodological issue. In our original study, the design was complicated by the presence of a "reference line" which was not on the iso-eccentric arc. The 2-line spatial interval and alignment data of Levi and Klein (1989a) that are summarized by the two lines in Fig. 1 do not share this complication. The targets consisted of only two short lines, and *both* were presented on the iso-eccentric arc. These 2-line experiments show that the failure of Weber's law observed at large separations was *not* a consequence of the middle line. Levi et al. (1988) argued that the eccentricity of the middle line might have the effect of elevating thresholds at the smallest separation which they tested (2 deg). Our 2-line data show no elevation of thresholds at small separations, suggesting that Levi et al.'s (1988) reasoning was correct.

The edges of the screen might also provide a reference whose effect can change for different separations. The screen edges are unlikely to provide a useful reference in our experiments for the following reasons: (1) the position of the stimuli were jittered relative to the fixation point and screen edges by several times the threshold; (2) when we halved the viewing distance for the 3-line experiments, thresholds were unchanged; (3) for the 2-line experiments the field size was approximately three times the largest separation (the 180 deg condition) so the edges were quite distant. For example, at an eccentricity of 10 deg the field size was 56 deg. The visibility of the edges was low since the target consisted of bright short lines on a dark background and the room illumination was kept low.

"Resolution failure" at small separations

Morgan and Watt's suggestion that the elevation of our bisection thresholds at a separation of 2 deg is due to a "resolution failure" is untenable on several grounds. First, we have measured DL's 2-line resolution thresholds at an eccentricity of 10 deg, and find them to be about 0.05 deg, 40 times smaller than the 2 deg separation. Second, at still smaller separations (less than 2 deg) our bisection threshold decline, in accordance with Weber's law. Moreover, our 2-line data (Levi & Klein, 1989a) show no elevation of thresholds at small separations. Thus we conclude that our bisection thresholds were elevated at a separation of 2 deg because of a small additive effect of the eccentricity of the middle reference line (Levi et al., 1988). Since the outer test lines were always at a larger eccentricity (the nominal eccentricity of the iso-eccentric arc), the uncertainty with which they could be localized always provided the principal constraint on the precision of spatial localization.

Relation to previous work by Beck and Halloran

Morgan and Watt (1989) criticized us for not considering the data of Beck and Halloran (1985), who tested 2-dot orientation discrimination with pairs of dots on the vertical meridian in the lower visual field separated by 0.75, 1.5 and 3 deg, with the bottom dot at one of three eccentricities, 4, 6 or 8 deg. Our 2-mechanism model makes very specific predictions about the interactions between separation and eccentricity for the Beck and Halloran conditions, and these are illustrated in Fig. 2. The solid line with positive slope shows the predicted sensitivity of the eccentricity mechanism, i.e. $Th = f(E + 0.6)$ deg. This "eccentricity" mechanism's sensitivity provides an upper limit to the thresholds, independent of separation. The precise value of f (the fraction of eccentricity) is dependent upon the task. For 2-line spatial interval discrimination, f was approx. 0.03 (Levi & Klein, 1989a). For 3-line bisection, it was 0.016, about a factor of two better (Levi et al., 1988; Levi & Klein, 1989a), while for 3-line alignment it may be as good as 0.007 (Klein & Levi, 1987; Levi & Klein, 1989a). Another factor affecting the value of f is whether

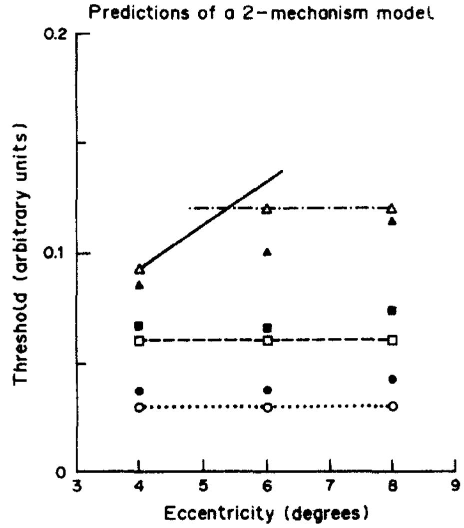

Fig. 2. Our 2-mechanism model makes very specific predictions about the interactions between separation and eccentricity (see text for details). The solid line shows the predicted sensitivity of the eccentricity mechanism, i.e. $Th = f(E + 0.6)$ deg. For purposes of illustration, we have plotted the solid line with $f = 0.02$. This "eccentricity" mechanism's sensitivity is independent of separation. The dotted, dashed and dot-dashed lines show the predicted sensitivity of a Weber's law mechanism where $Th = S/25$, for separations (S) of 0.75, 1.5 and 3 deg. Our hypothesis is that for any particular combination of separation and eccentricity, *the more sensitive of the two mechanisms will determine the threshold.* For the experiments of Beck and Halloran (1985), at separations of 0.75 and 1.5 deg, the ratio S/E is less than 0.4 so the thresholds will be proportional to separation, and show no dependence on eccentricity. Their largest separation (3 deg), has a ratio greater than 0.67 only at the smallest eccentricity (4 deg), and the threshold for this point will be based upon the target eccentricity. At the largest eccentricity the S/E ratio is less than 0.4, so thresholds will be based upon the target separation. The intermediate eccentricity of 6 deg has a ratio near the critical point. The predictions of our two-mechanism model are shown (in arbitrary units) for separations of 0.75 (open circles), 1.5 (open squares) and 3 (open triangles) deg. For comparison the mean data of Beck and Halloran's two observers (from their Figs 5 and 6) are shown by the solid symbols. Note that as expected, at separations of 0.75 and 1.5 deg (solid circles and squares, respectively), their data show little effect of eccentricity, whereas at 3 deg (solid triangles), there is a marked effect of eccentricity.

the lines are oriented radially (Beck & Halloran, 1985) or isoeccentrically (see Yap, Levi & Klein, 1987b, for further details). As we shall see, the value of f is not crucial to our discussion, so we have plotted the ordinate in Fig. 2 using arbitrary units. The use of arbitrary units also allows us to ignore the 50% difference in sensitivity between Beck and Halloran's two observers.

The dotted, dashed and dot-dashed horizontal lines together with the unfilled small symbols, show the predicted sensitivity of a Weber's law mechanism where $Th = S/k$, for separations of 0.75, 1.5 and 3 deg respectively. S is the separation of the lines, and k is a constant. The value of k depends on the task. We found $k \approx 20$ and $k \approx 30$ for spatial interval and spatial alignment respectively (Levi & Klein, 1989a). Since the ordinate in Fig. 2 has arbitrary units the precise value of k is not critical.

Our hypothesis is that for any particular combination of separation and eccentricity, *the more sensitive of the two mechanisms will determine the threshold.* The data of Levi and Klein (1989a) suggest across several 2- and 3-line alignment and interval judgment tasks that when the separation, S, between the two outside lines is less than about 0.67 E (based on the 40 deg breakpoint of our isoeccentric data discussed earlier), the Weber's law mechanism will be more sensitive, and when S is greater than 0.67 E, the eccentricity mechanism will determine the thresholds, i.e.

$$\text{for } S/E < 0.67;\ Th = S/k;$$

$$\text{for } S/E > 0.67;\ Th = f(E + 0.6)\ \text{deg}.$$

For a 3-line experiment according to this rule-of-thumb the critical separation between the middle dot and the outside dot is 0.33 E which is half the separation between the outside lines.

For the experiments of Beck and Halloran (1985) with separations of 0.75 and 1.5 deg, the S/E ratio is less than 0.4 at each of the three eccentricities, so the thresholds should be proportional to separation, and show no dependence on eccentricity. Their largest separation (3 deg), had ratios of $S/E = 0.375$, 0.5 and 0.75 at eccentricities of 4, 6, and 8 deg respectively. According to our rule, the point at $E = 4$ deg should be in the Weber's regime as were the points with smaller separations. The point at $E = 8$ deg should be in the eccentricity regime so that the threshold should be below the Weber's law prediction. The final point at $E = 6$ deg has $S/E = 0.5$ which is close to the critical ratio. Beck and Halloran defined E to be eccentricity of the more distant of the two stimulus points. If the eccentricity had been defined at the mid-point then $S/E = 3/4.5 = 0.67$ and the point for $E = 6$ deg would be at the critical ratio.

The predictions of our two-mechanism model are shown by the small open symbols and by the lines for separations of 0.75 (open circles), 1.5 (open squares) and 3 deg (open triangles). For comparison, the mean data of Beck and Halloran's two observers (from their Figs 5 and 6) are shown by the solid symbols in Fig. 2. Our predictions are largely consistent with much of the data of Beck and Halloran (1985). For example, at separations of 0.75 and 1.5 deg (solid circles and squares respectively), as expected, their data show little effect of eccentricity, whereas at the 3 deg separation (solid triangles), their data is in reasonable agreement with the prediction, showing a marked effect of eccentricity. Our two-mechanism model predictions are also largely consistent with the data of Toet, Snippe and Koenderink (1988) and Palmer and Murakami (1987) at fixed separations. Levi and Klein (1989a) also discuss instances where these predictions fail (e.g. Burbeck, 1988).

Relationship to data of Morgan and Watt (1989)

We now examine why the experiments of Morgan and Watt (1989) on arc length discrimination produced results different from our experiments on chord length discrimination. We re-plotted some of Morgan and Watt's (1989) data in Fig. 1. Specifically, we have replotted the iso-eccentric curve length data of observer MJM from Morgan and Watt at eccentricities of 2 and 4 deg (their Fig. 3). Their data have been transformed in two ways in order to facilitate direct comparison: (1) rather than plotting the line-length values (their abscissa) we calculated the angle subtended between the endpoints of the lines and the fixation point, and have plotted these angle (separation) values on the abscissa; (2) Morgan and Watt specify their thresholds as the standard deviation of the psychometric function (i.e. $d' = 1$) whereas we specify our thresholds at $d' = 0.675$. Therefore we multiplied their threshold values by 0.675, and then divided the values by $Ecc + 0.6$ deg, in order to specify them as a fraction of "effective eccentricity". A comparison of their data with the two curves illustrated in Fig. 1 shows that at large separations their thresholds are about 2–4 times higher (worse) than our prediction and our 2-line separation data, and are indeed consistent with an asymptotic Weber fraction of about 0.05–0.08. Morgan and Watt's poor performance at large angles (long curves) as shown in Fig. 1, indicates that their curve length discrimination task is inherently difficult. We discuss next why the arc length task of Morgan and Watt is expected to require a good deal more cognitive processing than the chord length task of Levi et al. (1988).

An arc length task involves the measurement of the angle subtended by the two endpoints whereas the chord length task involves the measurement of the distance between the two endpoints. The arc length, l, can be calculated from chord length, c, according to the equation $l = 2r \sin^{-1}(c/2r)$, where r is the radius of the arc. For small arcs (when the subtended angle is less than about 45 deg) the two tasks are almost equivalent since an increase in arc length will cause a proportional increase in chord length. For larger arcs, however, an increase in arc length has a lesser effect on chord length. For arcs near 180 deg, for example, arc length can increase without any increase in chord length. The connection between arc length and chord length is degraded in the Morgan and Watt experiments because of the presence of jitter. The jitter adds noise to the estimate of the radius of the circle since the distance from the fixation point to the arc is varying. Since the distance between the two endpoints is a poor cue to arc length, the observer probably judges arc length in one of the following two ways: (1) the observer can assess the angle of tangent of the arc at the two endpoints and take the difference in the two angles. This difference equals the angle subtended by the arc. The Weber's law relationship found by Morgan and Watt corresponds to a fixed accuracy in judging the tangent angle of about 2 deg (corresponding to a 3 deg error in judging the difference in angles). That is, the result of Morgan and Watt can be understood in terms of the plausible assumption that the observers have a fixed threshold for angle judgements; (2) the observer can integrate the full arc length by stepping along the arc and measuring the full distance. This process could lead to a square root law rather than a linear Weber's Law, if the individual measurements were uncorrelated; however, correlated measurement errors could lead to the correct Weber's Law. Both of these methods for measuring *arc* length have a complexity that leads to a Weber relationship. In contrast, the measurement of *chord* length can simply be done by calculating the distance between the two endpoints, a much easier calculation since it is based just on the location of each of the two endpoints.

Rather than tapping the sensory limitations imposed by the target eccentricity, performance on the arc length task is constrained by the cognitive demands of the task, or by the difficulty of reconstruction. Since the full length of the arc must be calculated, it is not surprising that a Weber's law in terms of arc length results. The arc length Weber fraction of 0.05–0.08 places a floor on the ability of the observer to do the task so the eccentricity limit with Weber fractions as low as 0.015 (Levi & Klein, 1989a) was never approached. We suspect that this type of floor effect can be found in other tasks where the judgements are difficult. Consider, for example, making 2-dot Vernier (transverse position) judgements at a nonstandard angle such as 37 deg. Since there are no natural references as would be the case for the horizontal and vertical base orientations, we expect that the only way to do the task would be to compare the orientation to an uncertain reference orientation. This judgement would by its nature follow Weber's Law, with the position threshold being proportional to separation. Performance might be limited by the difficulty of the task (maintaining a stable reference at 37 deg) rather than by sensory limits imposed by the anatomy and physiology of the visual pathways. Our point is that for *precise* spatial discrimination, where the reference is not unstable, both the target separation and its eccentricity may impose sensory limitations on performance.

In their conclusions, Morgan and Watt (1989) emphasized the importance of the representational and reconstructive processes and cognitive factors that are necessary in accomplishing position judgements. We agree that these factors may play a role. In fact, Klein and Levi (1987), ended their Discussion by suggesting the possibility of cognitive factors in position tasks. Their data showed that thresholds are lower (better) for three-dot alignment judgements then for interval judgements. To the degree that alignment and interval thresholds are different, the simple *isotropic* cortical grain hypothesis is not feasible. Levi and Klein (1989a) provided further data showing a difference between alignment and interval thresholds using a strategy that distinguishes the effects of separation and eccentricity. They present a number of alternative hypotheses on the role of explicit and implicit references (cognitive factors) that can account for the differences between two-line and three-line alignment and interval tasks (Appendix, Levi & Klein, 1989a). These findings imply that the "cortical ruler" used for interval judgements and the "cortical ruler" used for alignment judgements have different sensitivities. In any case, whatever the role of higher order reconstructive processes and cognitive factors in position judgements, our data (Levi *et al.*, 1988; Levi & Klein, 1989a) show that for widely separated lines, interval judgements are proportional to the eccentricity of the lines and depend very little on their separation, implying that the cortical rulers do not follow Weber's law.

To summarize, we suggest that there are two sensory mechanisms, one dependent upon separation, the other dependent upon eccentricity, which can limit precise positional judgements (Klein & Levi, 1987; Levi et al., 1988; Levi & Klein, 1989a). The separation dependent mechanism produces the familiar Weber's law relationship between position thresholds and target separation, and operates at small separations. The eccentricity dependent mechanism operates to produce precise position judgements when the separation is comparable to the target eccentricity, and is consistent with Lotze's notion of local signs (localzeichen)—i.e. that the direction in which an object is perceived is an intrinsic property of the visual system. Finally, we wish to point out that we do *not* regard the Weber's law relationship for position as an "artefact of eccentricity" (Morgan & Watt, 1989), rather we suggest that both the target separation and eccentricity can impose sensory limitations on the precision of positional acuity, and thus contribute to the Weber fraction for position (Klein & Levi, 1987; Levi & Klein, 1989a, b).

Acknowledgement—This work was supported by grants R01 EY01728 and R01 EY04776 from the National Eye Institute.

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