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Suppression of Visible Persistence

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Five experiments were conducted to examine duration of visible persistence in sequences of stimuli. The basic display consisted of a point that stepped around a circular path on the face of an oscilloscope. Observers estimated the number of points seen simultaneously. Results were compared with a control condition in which the points were plotted in random order rather than sequentially. It was found that visible persistence of a point is suppressed if other points are shown nearby and after an appropriate delay. The degree of suppression depended on the spatial proximity of successive points. It was also found that both duration of visible persistence and degree of suppression increase with eccentricity in the visual field. The results are discussed in terms of two independent processes, persistence and suppression, that operate in a hierarchically antithetical relation.

A brief visual display of less than about 100 ms typically appears to last somewhat longer. Visibility beyond the actual duration of the display is known as *visible persistence.*

Because of visible persistence, two stimuli presented at slightly different times may be seen as temporally overlapping. This effect has been used in several studies to estimate the duration of visible persistence (e.g., Dixon & Hammond, 1972; Efron & Lee, 1971). In these studies, a rotating radial line was illuminated stroboscopically, and observers were required to estimate the number of lines that were visible simultaneously. Duration of visible persistence could then be inferred from the observers' responses and from the frequency of illumination.

A variant of this technique was employed by Allport (1968), who displayed a single horizontal line stepping through successive vertical positions on the face of an oscilloscope. The display was continuously cycled so that, at low stepping rates, a line was seen moving repeatedly from bottom to top of the screen. As the stepping rate was increased, a point was reached at which lines were seen at all positions simultaneously. This point was taken as an index of the span of simultaneity. Equivalently, it may be regarded as providing an index of the duration of visible persistence.

Techniques such as these have been used successfully for investigating the effects on persistence of such variables as stimulus luminance, background luminance, and presentation rates. The major purpose of the present work is to adapt this paradigm for studying the effects of variables that hitherto have received less attention. More specifically, we wish to examine how spatial proximity and temporal contiguity of successive stimuli interact in determining the duration of visible persistence. These spatiotemporal factors deserve scrutiny because they may be central to an understanding of such effects as metacontrast masking (e.g., Kahneman, 1968) and the suppression of visible persistence that is experienced in the perception of objects in motion (e.g., Burr, 1980).

The present work begins from an observation, noted but not elaborated by Allport (1968), concerning the effect of spatial separation between successively displayed lines on the duration of visible persistence. Allport observed that, as the lines were spread further apart, estimates of persistence increased ac-

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cordingly. This observation was confirmed in more systematic studies by Dixon and Hammond (1972) and by Farrell (1984).

To investigate the effect of spatial separation, we employed a point stepping around a circular path, rather than a line moving across the screen or rotating about a central location. The punctate display was preferred because both forms of line display involve a range of retinal eccentricities that would confound the effect of spatial separation. It is known that the temporal characteristics of vision vary with retinal eccentricity (e.g., Granit & Davis, 1931). In addition, discrete separations cannot be achieved with the radial line display, which, by its construction, defines a range of retinal separations between corresponding points in successive radial lines ranging from zero in the center of the display to maximum at the periphery.

Experiment 1 was designed to confirm the relation between spatial separation and duration of visible persistence under the more controlled conditions afforded by punctate stimuli. Further, it was designed to provide a basis for assessing the effects of the variables examined in the succeeding experiments.

Experiment 1

In our display, the points moved around a circular path in steps whose length varied according to the condition. Regardless of length of step, however, the temporal interval, or stimulus-onset asynchrony (SOA) between the plotting of successive points was held constant at 55 ms.

Two outcomes seem possible in this experiment, depending on whether spatial proximity affects duration of persistence. One outcome is based on the view that the number of points seen simultaneously is simply the number contained at any one time within a temporal window whose duration has been estimated at about 100–150 ms (Coltheart, 1980). On this view, the number of points visible at one time would depend not on spatial separation but on the number of points plotted within the duration of the temporal window. The alternative outcome, based on the work cited above, is that duration of persistence should be directly related to the size of the step and that the number of points visible simultaneously should vary accordingly. The results revealed strong effects of spatial separation.

Method

Observers. The first author and 3 students, naive as to the purpose of the work, served in all experiments except Experiment 5. All had normal or corrected-to-normal vision.

Visual display. The display consisted of a series of points plotted sequentially around a circular path on a Hewlett-Packard 1333A point-plotting oscilloscope equipped with fast P15 phosphor. From the viewing distance of 57 cm, the radius of the circular path was 0.4° of visual angle. Points were plotted counterclockwise for a single revolution around the circular path, beginning at the 3 o'clock position.

There were four levels of separation between successive points. These were obtained by evenly spacing 36, 18, 12, or 9 points around the circumference of an imaginary circle. For the size of imaginary circle employed here, these correspond to separations of 0.07°, 0.14°, 0.21°, and 0.27° of visual angle.

Design and procedure. The observer sat facing the oscilloscope at a distance of 57 cm, set by a headrest. Indirect background illumination was provided by a 40-W lamp in a corner of the room.

A fixation point was plotted at the center of the screen and remained on view throughout each trial. Observers viewed all displays binocularly and initiated a trial by pressing a hand-held pushbutton. After a button press, a point was intensified for 1 μs at the 3 o'clock position. After a stimulus-onset asynchrony of 55 ms, during which the screen remained blank except for the fixation point, the next point in the sequence was intensified. This cycle was repeated until all points had been presented.

After each trial, the observer indicated how many points were seen simultaneously. All four levels of separation occurred randomly within an experimental session. Each observer made 20 judgments for each level of separation.

Results and Discussion

Individual results for each of the 4 observers are shown in Figure 1. In every case, the number of points reported increased with interpoint separation. These results agree with the observations of Allport (1968), of Dixon and Hammond (1972), and of Farrell (1984).

Phenomenologically, the appearance of the displays was not unlike that reported in experiments employing radial lines (e.g., Efron & Lee, 1971). Depending on the condition, observers saw either a single point or a group of points moving in a circular path. It was noted that the quality of motion seemed poorer as more points were seen.

A perceptual moment hypothesis (Allport, 1968; Stroud, 1955) is unhelpful in interpreting these results. Even cursory calculation of the duration of the perceptual moment from an average of the data in Figure 1 would yield several different estimates (ranging from less than 55 ms to 131 ms). The estimate would depend on interpoint separation, a variable ostensibly irrelevant to the theory. Were the theory to be modified to accommodate the effects of spatial variables, little heuristic value would be retained.

At the simplest level, the data strongly suggest that duration of visible persistence is affected by the spatial proximity of successively presented stimuli. At the smallest separations, all observers consistently reported seeing a single point (Figure 1); at the largest separations studied, they saw two or three. When only one point is seen, duration of persistence cannot be longer than the SOA, namely 55 ms. At wider separations, where two or three points are reported, duration of visible persistence would be on the order of 110–165 ms.

Why is there less persistence at shorter separations? The higher values of persistence exhibited at the greater separations are in close agreement with the results of many other studies (Coltheart, 1980). This invites the hypothesis that the persistence of the stimuli displayed close together was, in some way, foreshortened. More generally, it may be suggested that the persistence of a stimulus is attenuated by the subsequent presentation of other stimuli in close spatial proximity.

Suppression of the persistence of temporally leading stimuli would be natural in the con-

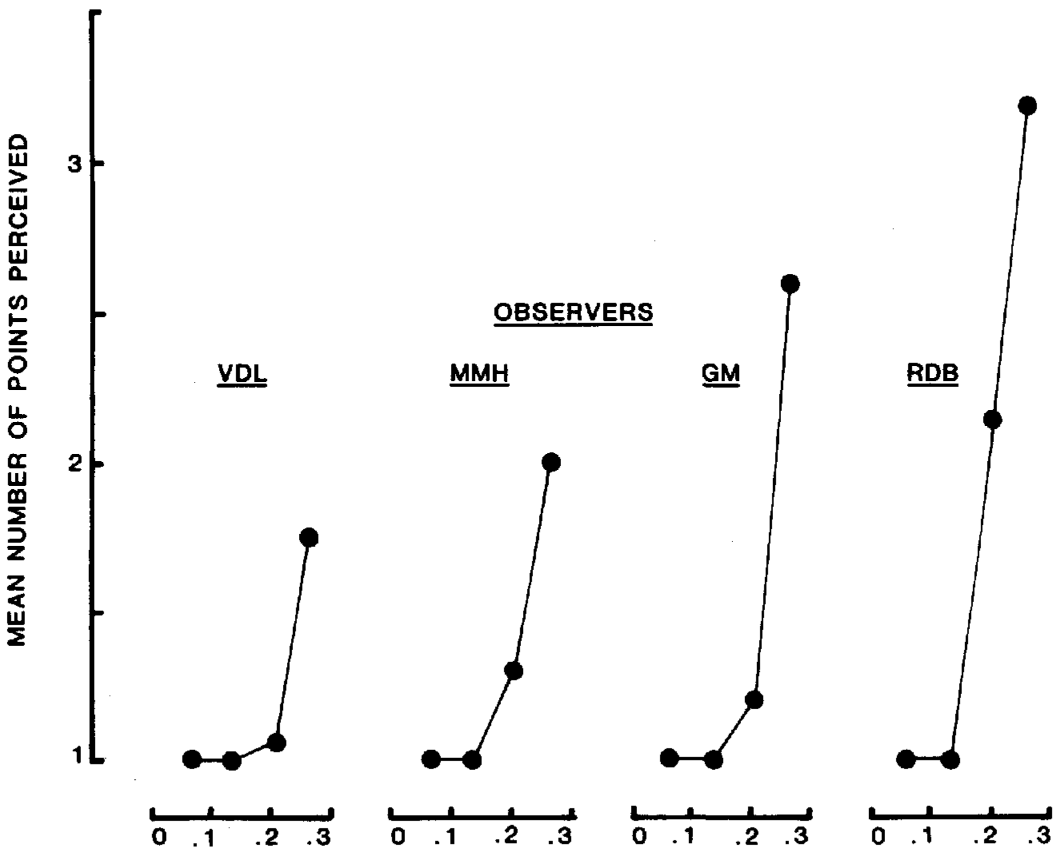

Figure 1. Mean number of points seen simultaneously as a function of interpoint separation for 4 observers in Experiment 1.

text of elimination of smear in motion perception (Burr, 1980) and in the context of metacontrast masking (Breitmeyer, Love, & Wepman, 1974; Hogben & Di Lollo, 1984). Before pursuing this line of reasoning, however, it is necessary to ensure that the outcome of Experiment 1 was not due to a confounding between interpoint separation and other parameters in the display. This is done in Experiment 2.

Experiment 2

Interpoint separation in Experiment 1 covaried with two other varibles: total number of points in the display sequence and total duration of the display. As interpoint separation was reduced from 0.27° to 0.07° of visual angle, the total number of points plotted increased from 9 to 36, and the total duration of the display increased from 440 to 1,925 ms.

To ensure that the observers' responses were unaffected by these confounding variables, Experiment 1 was replicated under conditions in which all displays contained identical numbers of points and lasted for identical durations. To meet these requirements, only nine points were plotted in each condition, regardless of interpoint separation. The nine points were plotted around a complete circle only at the largest separation of 0.27°. At smaller separations, the nine points were plotted around a correspondingly smaller section of the circular path.

Method

The method employed in Experiment 2 was the same as in Experiment 1, with the following exception. All displays began at the 3 o'clock position and continued counterclockwise until nine points had been presented. At the widest interpoint separation of 0.27° of visual angle, the points were plotted around the whole circular path. At separations of 0.21°, 0.14°, and 0.07°, the nine points covered only three quarters, one half, or one quarter of the circular path.

Results and Discussion

Individual results of Experiment 2 are shown in Figure 2, which also contains the corresponding data from Experiment 1 to facilitate comparison. It is immediately apparent that the outcomes of the two experiments are the same and that the data lie comfortably within the bounds of replication.

Given the similarity of the two outcomes, we may be confident that the number of points visible at one time is a function of interpoint separation and is unrelated to the total number of points or to the total duration of the display. In turn, the suppression hypothesis outlined in the discussion of Experiment 1 remains viable.

It is hypothesized that the reduction in number of simultaneously visible points was due not to a running out of visible persistence but to an active process of suppression. The suggestion is that if a point is displayed briefly and in isolation, it will exhibit persistence of about 100–150 ms; however, if one or more additional points are presented nearby and soon after, the persistence of the first point is suppressed. That is to say, the suppression of visible persistence observed in these experiments depends on the spatial proximity of successive points plotted at a suitable delay.

Just how much suppression was obtained in Experiments 1 and 2 cannot be assessed without knowing just how long visible persistence would be in this paradigm without the effect of suppression. In Experiment 3 we set out to estimate the duration of visible persistence under conditions as close as possible to those of the first two experiments. To a first approximation, the baseline of persistence may be obtained by presenting the points in random order rather than sequentially. To the extent that spatial proximity at an appropriate delay underlies suppression, disruption of the spatiotemporal contingency should allow persistence to continue unchecked.

Displaying the points in random order also has the effect of disrupting coherent apparent motion, which was conspicuous in the displays of Experiments 1 and 2. Strong correlative links have been established between the appearance of motion and the occurrence of suppression in phenomena such as metacontrast (Breitmeyer, Battaglia, & Weber, 1976; Hogben & Di Lollo, 1984). Even though no causal relationship has been established (and it is not the purpose of the present work to examine this question), the elimination of coherent motion through random presentation of the points is a sensible precaution in securing the best possible estimate of visible persistence.

Experiment 3

The sequential mode of presentation in the previous two experiments was replaced in Experiment 3 by a random order. Except for the sequence in which the points were displayed, Experiment 3 was a faithful replication of Experiment 1.

Random presentation of the points had two effects: It disrupted the appearance of coherent motion, and it increased the average spatial separation between consecutive points. Separation varied randomly between minimum values corresponding to the interpoint separations in Experiment 1 and a maximum of 0.8°, the diameter of the circle around which the points were located. Although this procedure cannot be guaranteed to eliminate suppression, it should reduce it by reducing the spatial proximity of successive points while preserving the geometry and the timing of the stimuli employed in Experiment 1.

Method

The method employed in Experiment 3 was the same as in Experiment 1 except that the points in each display were presented in random order rather than sequentially. A new random order was chosen for each trial.

Thirty-six, 18, 12, or 9 points were located at equal intervals around the circumference of an imaginary circle. The points were intensified in random order at

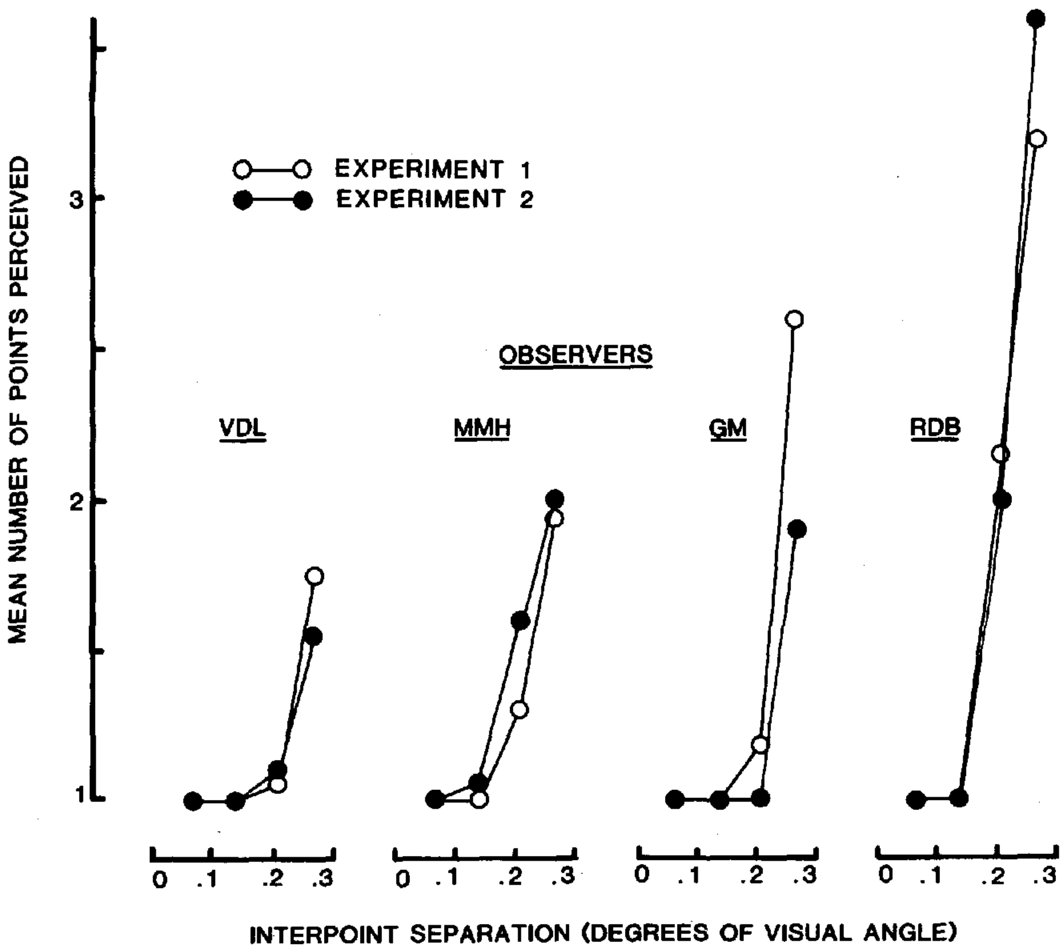

Figure 2. Mean number of points seen simultaneously in Experiment 2 (filled circles) and in Experiment 1 (open circles).

intervals of 55 ms. Thus, both the spatial locations of the points and the rate at which they were presented were the same as in Experiment 1. What changed was the spatiotemporal contingency: In Experiment 3 the display could begin at any location, and any of the remaining points had an equal chance of being intensified next. So, while the separation between locations around the imaginary circle remained the same as in Experiment 1, the actual spatial separation between consecutive points in a display sequence varied randomly.

Results and Discussion

Individual results are shown in Figure 3, with the corresponding data from Experiment 1 included for comparison. It is clear that random plotting dramatically increased the number of points visible simultaneously, a result obtained also by Morgan and Watt (1983) under similar circumstances. Since an average of 2.8 points were seen under random presentation, duration of visible persistence may be estimated at between 99 and 154 ms (i.e., between 1.8 × 55 and 2.8 × 55). This estimate is in line with currently accepted values (e.g., Efron, 1973), suggesting that random presentation of the points was successful in averting the suppressive effects seen in Experiment 1.

In comparing the curves for Experiments 1 and 3 in Figure 3, it should be made clear that the interpoint separations shown on the abscissa apply to the two experiments in a spatial but not in a temporal sense. That is, the values shown on the abscissa represent spatial separations between neighboring locations at which points could potentially be displayed. In the case of Experiment 1, these

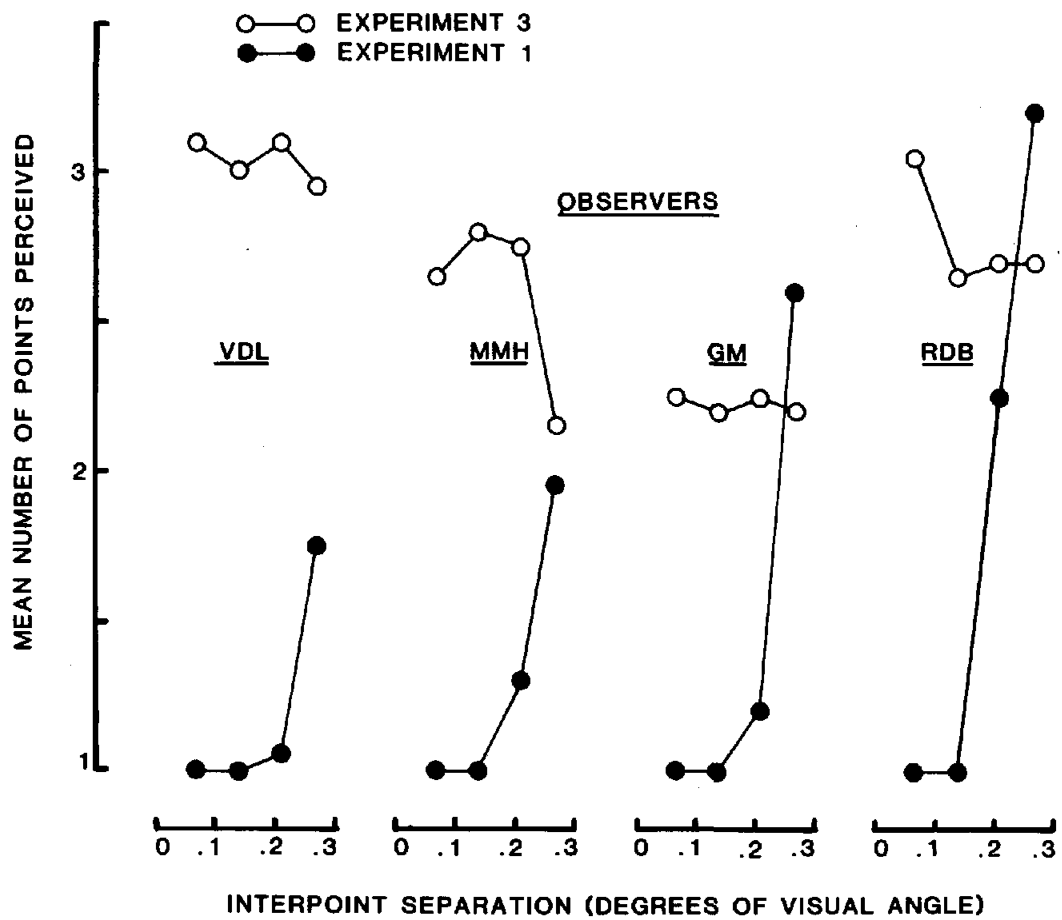

Figure 3. Mean number of points seen simultaneously with random plotting order (open circles) in Experiment 3. (The results of Experiment 1 [filled circles] are shown for comparison.)

coincided with the separations of successive points within the plotting sequence. However, in Experiment 3, the separation between successive points varied randomly within the ranges mentioned above, with the result that direct comparisons between corresponding points on the two sets of curves cannot be made in a straightforward fashion.

It is of interest to note that the average separation between successive points in the random condition was approximately 0.55° at all interpoint separations (the standard deviation was also approximately constant at 0.23°). Thus, random and sequential conditions differed both in respect to average separation between successive points (which was much larger in the random condition) and in respect to order of plotting. The present experiment was not designed to unconfound the two variables; hence, it is impossible to say whether the release from suppression was due to the random nature of the presentation or to the large average separation. However, as can be seen in Figure 3, duration of visible persistence remained at approximately the same level across all random conditions, suggesting that the effect is probably controlled by interpoint separation.

Using the estimate of 99–154 ms as the baseline level of persistence, it can be seen that the effect of suppression was largely confined to small interpoint separations in Experiment 1. At the two smallest separations, no observer ever reported seeing more than one point, suggesting persistence of much less than 55 ms, a duration completely out of line with current estimates. In this light, the inference is all but inescapable that a process of perceptual suppression is at work to inhibit the visible persistence of a point when it is followed by one or more other points nearby and at an appropriate delay. The question of why suppression seems to operate at short but not at long interpoint separations is raised and examined in the General Discussion.

Experiment 4

Experiment 4 was designed to examine how duration of visible persistence and degree of suppression vary with retinal eccentricity.

An advantage of punctate stimuli over radial lines is that they permit us to specify precisely the retinal eccentricity at which the display is to be presented. In the present experiment, four levels of retinal eccentricity were combined factorially with four radial separations of points. All combinations were displayed under sequential conditions, as in Experiment 1, and under random conditions, as in Experiment 3.

Method

The method of Experiment 4 combined the procedures employed in Experiments 1 and 3 and replicated them at four additional eccentricities. Eccentricity was varied by plotting points around circular paths having radii of 0.7°, 1.0°, 1.3°, and 1.6° of visual angle. In every case interpoint separation was varied by plotting 36, 18, 12, or 9 points, evenly spaced around the circumference of an imaginary circle. The actual interpoint separations (in degrees of visual angle) covaried with eccentricity of the display. However, comparison across eccentricities at given interpoint separations is possible as illustrated in Figure 4.

Within an experimental session, stimuli were presented at only one eccentricity and with one method of plotting (sequential or random). Interpoint separations were presented randomly within a session.

Results and Discussion

The results of Experiment 4, averaged over all 4 observers, are shown in Figure 4. The results of Experiments 1 and 3, averaged across observers, are also included. The group data are representative of the individual results.

In the random presentation conditions (Figure 4, open circles) the number of points seen simultaneously increased with the eccentricity of the display. The mean number of points rose from 2.7 at an eccentricity of 0.4° to 3.4 at an eccentricity of 1.6°, corresponding to durations of visible persistence in the ranges of 94–148 ms and of 132–187 ms. Clearly, persistence lasts longer at the periphery than at the fovea. Intuitively, this psychophysical relationship invites reference to a well-known fact of retinal physiology, namely that size of receptive field increases with eccentricity. We mention this correlative relation in the hope that someone might identify a corresponding causative relation, for none is immediately apparent to us. In further work, it may be of interest to scale interpoint separation at different eccentricities in terms of the cortical magnification factor (e.g., Tyler & Silverman, 1983) to ascertain whether the increments in persistence can be accounted for in terms of receptive field size. Increased persistence at the periphery is also in suit with Adelson's (1978) observation that rods show more visible persistence than do cones, although this is not to suggest that the locus of visible persistence is retinal.

In the sequential presentation conditions (Figure 4, closed circles), each of the five curves shows strong evidence of suppression. At each eccentricity, the mean number of points reported was invariably less under sequential than under random presentation. As in Experiment 3, the effect was most marked at shorter interpoint separations.

A notable feature of Figure 4 is that, to a close approximation, the curves for sequential and for random presentation converge to common levels that depend upon the eccentricity of the display. The levels of convergence are higher as eccentricity increases because, as noted above, persistence is greater as distance from the fovea increases. It is from these levels that decrements can occur as suppression exerts its effect. The curves for

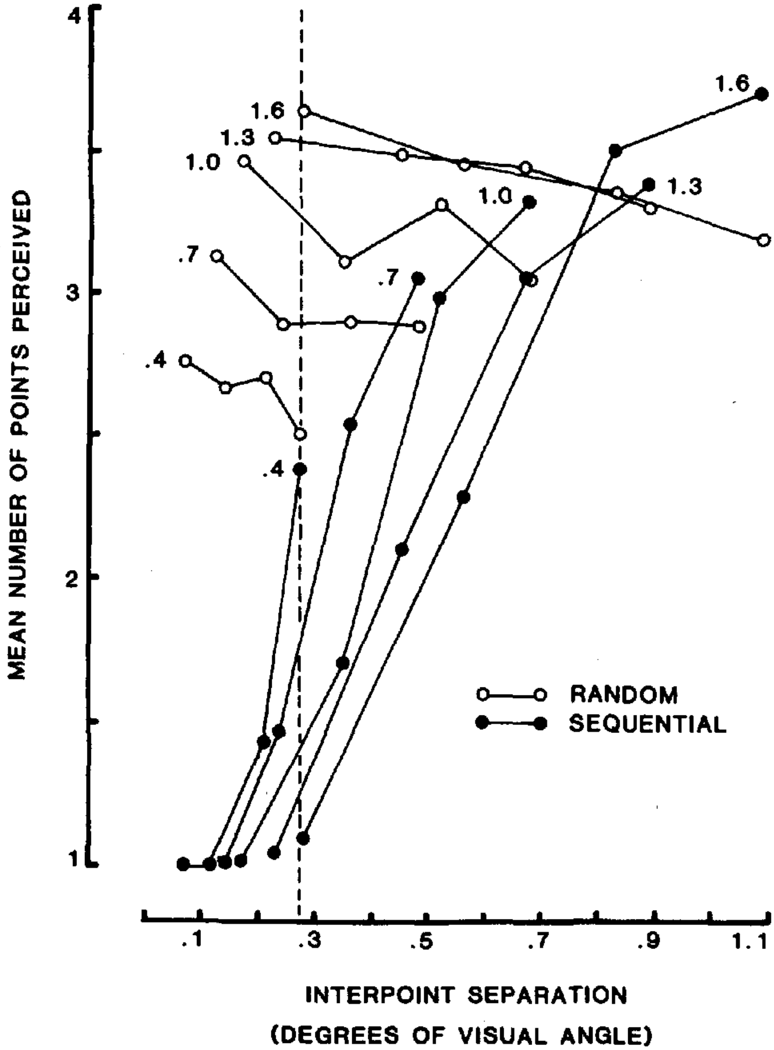

Figure 4. Effect of random plotting order (open circles) and of sequential plotting order (filled circles) at five retinal eccentricities.

sequential presentation may now be described as a family of suppression functions, representing increasing severity of suppression as interpoint separation decreases. The highest level reached by each sequential curve is set by the duration of persistence that would obtain at the appropriate eccentricity when little or no suppression is present. Within each curve, suppression increases with proximity of successive points and, in turn, reduces the number of simultaneously visible points to the irreducible minimum of one.

A striking aspect of the data becomes apparent when we ask how degree of suppression is related to retinal eccentricity. We find that, for any given interpoint separation, suppression increases from the fovea to the periphery. This may be illustrated by drawing an ordinate through all the curves. In Figure 4 an ordinate (segmented line) was drawn at a retinal interpoint separation of 0.28° in order to intersect all 10 curves. At this ordinate, the curves for random presentation are ordered from foveal (lowest) to most peripheral (highest), reflecting increasing duration of visible persistence toward the periphery. By contrast, the order is exactly reversed for the sequential-presentation curves. This reversal of order provides the clearest possible evidence that suppressive effects increase with retinal eccentricity. Plainly, the eccentricity that produces the highest estimate of persistence under random presentation yields the lowest estimate under sequential presentation.

It is known that spatial resolution decreases with eccentricity (Woodworth & Schlosberg, 1954) so that a given interpoint separation at the fovea is functionally equivalent to a larger separation more peripherally. It is also known that foveal-peripheral differences in temporal resolution (e.g., critical fusion frequency) can be compensated by scaling the size of the stimuli to correct for spatial resolution. It is quite possible that the increasing function of suppression with eccentricity illustrated in Figure 4 can also be eliminated if interpoint separation be scaled to take account of diminishing spatial resolution with retinal eccentricity (cf. Johnson & Massof, 1983). Put another way, it is possible that degree of suppression may be the same foveally and peripherally, provided that the separation between adjacent points is adjusted to take into account the cortical magnification factor.

Experiment 5

In Experiment 4, observers viewed points stepping around circles of different sizes. The smallest circle was wholly within the fovea, the largest well into parafoveal areas. Maintenance of fixation within a trial was reportedly easier with the smaller displays. Experiment 5 examines whether reasonable fixation could be maintained with the larger displays and how a tendency to track the moving point would affect the number of points seen simultaneously.

One observer from the previous experiments performed a partial replication of Experiment 4 while his eye movements were monitored. Judgments were made at an eccentricity of 1.6° under two conditions: In one condition the observer was required to maintain central fixation as in the previous experiments; in the other the observer attempted to track the point as it moved around the circular path.

Method

One observer (VDL) viewed the display with his head movements constrained by a bite bar and a headrest. Eye movements were monitored with a model RK-416 Pupil Tracking System manufactured by Iscan Inc. The stimuli were the same as in the sequential plotting condition in Experiment 4 at an eccentricity of 1.6°. In separate sessions, the observer was required to maintain fixation as in the previous experiments or to track the moving point. On each trial, eye position was sampled synchronously with the plotting of a point. There were 10 trials at each of the four interpoint separations in each tracking condition.

Results and Discussion

Figure 5 shows mean eye position averaged over the 10 trials at an interpoint separation of 0.28° of visual angle, under both tracking conditions. It is plain that, while tracking instructions produced a record that approximated the circular path of the moving point, fixation remained stable when the observer was instructed not to track. It is interesting to note that trials conducted with longer SOAs produced deliberate eye movements whose path more closely approximated the path of the moving point, without affecting accuracy of central fixation.

Figure 6 shows the mean estimated number of points under tracking instructions (closed circles) and under no-tracking instructions

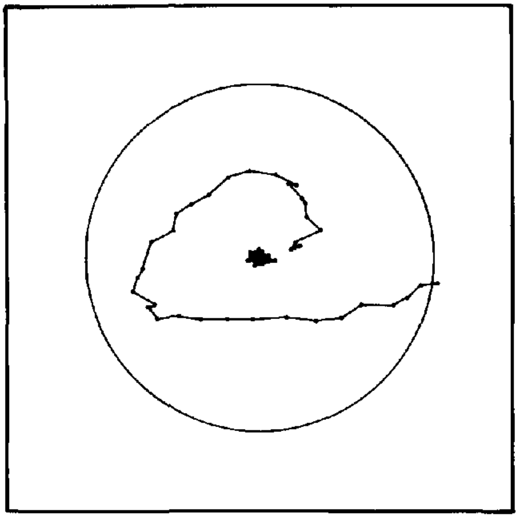

Figure 5. Eye-movement records under conditions of steady fixation (central blob) and of deliberate tracking. (The outer circle represents the path of the moving point.)

(open circles). Also included in Figure 6 are the results for this observer in the corresponding conditions of Experiment 4 (open triangles).

It is immediately evident that when the observer was instructed to fixate, the results were very similar from one experiment to the other, regardless of whether eye movements were being monitored (Figure 6, open symbols). On the other hand, the number of points reported when the observer tracked the moving point was considerably smaller (Figure 6, filled circles). This outcome can be at least partly understood if it is realized that, as was shown in Experiment 4, duration of visible persistence is briefer at the fovea. As a result of tracking, the moving point was maintained closer to the fovea throughout the trial, and persistence was correspondingly brief.

Be that as it may, the main point of this experiment is that the results of the previous studies can be replicated when fixation is monitored. We can, therefore, be confident that eye movements played no significant role in the preceding experiments.

General Discussion

Three main findings emerge from the present work: First, duration of visible persistence increases from the central fovea toward the periphery; second, strength of suppression follows a similar topological course; third, within the temporal constraints of the present studies (SOA = 55 ms), suppression is confined to interpoint separations not exceeding approximately half a degree of visual angle.

How can these findings be encompassed within existing theoretical frameworks of persistence and of suppression? Although visible persistence has been regarded as the decaying contents of a sensory store (e.g., Neisser, 1967), we follow more recent theorizing (e.g., Di Lollo, 1980; Meyer, 1983) that treats persistence as the product of activity at one or more information-processing nodes within the visual system. Under conditions that minimize inhibitory spatiotemporal interactions (e.g., Efron, 1973), persistence continues until processing within these nodes is completed. Under these conditions, duration of visible persistence has been estimated at 100–150 ms (Coltheart, 1980).

Visible persistence of this duration, however, would produce noticeable smear of moving objects, even at the moderate velocities encountered in everyday experience. Were persistence to operate unchecked, most of our perceptions would be blurred by motion, either of objects or of the eyes. Clearly, a mechanism of suppression is required to clean up and sharpen the visual image. The action of just such a mechanism is illustrated in the work of Burr (1980) and of Farrell (1984). The present research confirms this and furthermore reveals the antithetical relation between suppression and persistence as a function of interpoint proximity and of retinal eccentricity. It may be suggested that this suppressive effect could be related to the elevation of threshold during saccadic movements (Matin, Clymer, & Matin, 1972). However, it is unlikely that the two phenomena share the same mechanism, because saccadic suppression appears to operate over much greater spatial ranges than does the present effect (MacKay, 1970).

On rational and empirical grounds, we regard persistence and suppression as separate perceptual processes. We suggest that the two processes stand in a hierarchically antagonistic relation. Although suppression can interfere with persistence, the reverse does not occur. Either visible persistence runs its natural course, or it is terminated if other stimuli occur nearby and soon after.

Even though the psychophysical evidence for a suppressive mechanism is compelling, its physiological basis is not clear. It is known that lateral inhibitory interactions occur centrally as well as peripherally, and it is quite plausible that the present effects may stem from interactions at any of these levels. Certainly, the limited spatial range of the suppressive effects is consonant with expectations from a lateral inhibition hypothesis.

In a broader context, the suppression demonstrated in these experiments may be regarded as belonging to the class of events subsumed under the rubric of backward visual masking. Strong parallels have been drawn between the perceptual suppression obtained

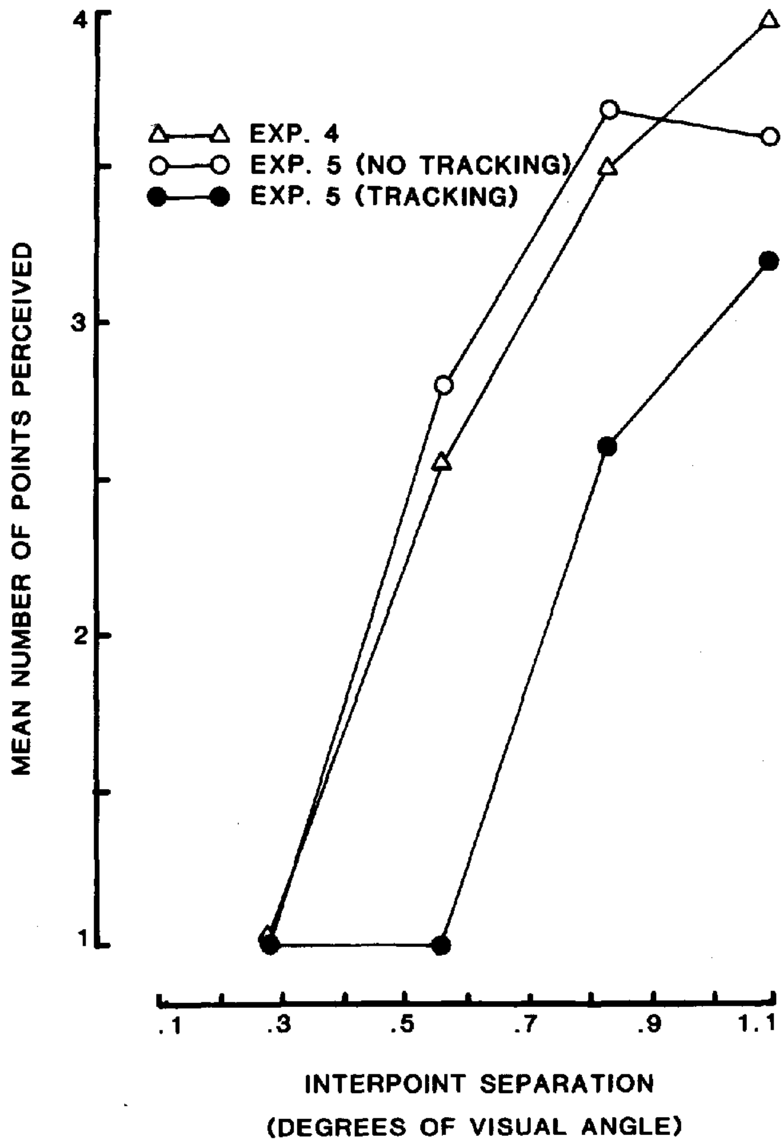

Figure 6. Mean number of points seen simultaneously in Experiment 5 under conditions of tracking (filled circles) and of steady fixation (open circles). (The results of the corresponding condition in Experiment 4 [open triangles] are included for comparison.)

in metacontrast masking and in apparent motion between two stimuli (Breitmeyer, Love, & Wepman, 1974; Hogben & Di Lollo, 1984). In both cases, perception of the temporally leading stimulus is suppressed by presentation of a second stimulus in the appropriate spatiotemporal relationship. Indeed, we have suggested that the suppressive effects in metacontrast and in apparent motion are produced by a common mechanism (Hogben & Di Lollo, 1984). We now suggest that much the same mechanism underlies the suppressive effects demonstrated in the present work. Although still in need of empirical confirmation, this suggestion is buttressed by the fact that the suppressive effects, whether in metacontrast or in the present paradigm, increase markedly in parafoveal compared to foveal locations. Both phenomena are also amenable to explanation in terms of lateral inhibitory interactions.

An alternative interpretation of these results has been brought to our attention by Morgan (personal communication, June 1984). The model, outlined by Morgan and Watt (1983), accounts for the perception of moving sequences in terms of independent spatial and temporal filters. Initially, the model was developed to explain the *interpolation effect,* which is obtained in vernier acuity tasks if the component bars are shown in apparent motion through a series of successive stations. Under appropriate spatiotemporal conditions, observers interpolate the positions of the bars between their actual positions. The spatiotemporal upper limits of the effect (about 3 to 4 arc min, and about 30 ms) are determined by the space- and time-constants of the two filters. Successive stimuli that fall within the spatiotemporal limits of the filters are not resolved but are seen as a single stimulus in motion. More specifically, "The temporal filter causes the information from several successive stations to persist; these are then filtered by a DOG (difference of Gaussian) filter, and provided the output of the latter does not contain multiple zero crossings, only one target is seen" (Morgan, personal communication, June 1984). As a consequence, ". . . the momentary position of an apparently moving target is not its most recently presented actual position, but rather its interpolated position" (Morgan, 1979, p. 491). The interpolation effect thus depends on failure of resolution, whereby only one stimulus is seen instead of the persisting traces of the stimuli at several locations.

In Morgan's view, the interpolation effect and the suppression effect are very closely related and may be identical. We concur with the notion that "suppression of persistence" and "failure of resolution" are alternative ways of considering the present work. Our data do not provide a basis for choosing either mode of description, although two points bear mention. First, both the spatial and the temporal parameters employed in the present work lie outside the limits of the filters described by Morgan and Watt (1983). They find that the interpolation effect decreases beyond a temporal interval of 30 ms and vanishes by 50 ms; consequently, failure of resolution is not to be expected at the temporal interval of 55 ms employed in the present work. Similarly, suppression effects were obtained in the present work at interpoint separations of at least 40 arc min, about 10 times the suggested constant of the spatial filter. These, however, are matters of detail: Temporal and spatial constants may well vary according to experimental conditions. For example, the size of the filter may increase toward the periphery.

Second, in its current version, the filter model has difficulty in accommodating our findings that both suppression and persistence increase towards the periphery. To account for increased suppression (i.e., greater failure of resolution), the model must postulate larger filter sizes, but to account for increased persistence, smaller filters are called for.

One last point needs to be added. In all the experiments reported here, the SOA between successive points was fixed at 55 ms. However, the pattern of results is not peculiar to this SOA. We have performed pilot replications of the present studies at SOAs ranging from 40 to 85 ms without changing the broad pattern of the results, other than in entirely predictable ways (e.g., more points were seen overall at the shorter SOAs, and fewer at the longer SOAs). There were also other systematic changes wrought by variations in SOA, including an interaction between SOA and spatial proximity, reminiscent of the spatiotemporal relation expressed in Korte's now questioned third law (Caelli & Finlay, 1981). Elucidation of this relation, however, requires further empirical work.

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