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Frank H. Durgin

Swarthmore College, fdurgin1@swarthmore.edu

Sarah E. Wolfe , '97

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Frank H. Durgin and Sarah E. Wolfe , '97. (1997). "Global Precedence In Visual Search? Not So Fast: Evidence Instead For An Oblique Effect". *Perception*. Volume 26, Issue 3. 321-332. DOI: 10.1068/p260321 <https://works.swarthmore.edu/fac-psychology/136>

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Durgin and Wolfe 1997

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Draft version

Published version: Forthcoming in *Perception*

Global Precedence In Visual Search? Not So Fast:

Evidence Instead For an Oblique Effect

Frank H. Durgin and Sarah E. Wolfe

Department of Psychology, Swarthmore College

Send correspondence and requests to: fdurgin1@swarthmore.edu

Frank H. Durgin

Department of Psychology

Swarthmore College

500 College Avenue

Swarthmore, PA 19081

USA

phone: (610) 328-8678

fax: (610) 328-7814

Abstract

The authors reexamine the evidence from an earlier report of global precedence in visual search (Saarinen 1994). Two new experiments are reported. The first experiment indicates that the confusability of oblique orientations (a class 2 oblique effect, Essock 1980) rather than global precedence was responsible for the earlier results. The second experiment shows that the effect critically depends on the presence of heterogeneous distractors rather than on differences in raw processing speed for different spatial scales. The possible role of symmetry is discussed.

1 Introduction

Saarinen (1994) recently reported results of a visual search task in which targets could be defined by differences either in local or in global orientation. Representative displays are shown in Figure 1. Saarinen found that search for a globally-horizontal bar among globally-vertical bars was more efficient than search for locally-left-diagonal lines among locally-right-diagonal lines. Saarinen described this as a global precedence effect. However, a difficulty with interpreting Saarinen's finding is that cardinal orientations such as vertical and horizontal are special both neurally and linguistically, whereas oblique lines seem to pose certain kinds of perceptual difficulties ("*the oblique effect*" -- Appelle 1972; Essock 1980; Callaghan Lasaga and Garner 1986; Lasaga and Garner 1983). In general, the *confusability* of left-diagonals and right-diagonals is known as a class 2 oblique effect (Essock 1980), which can also be understood as a mirror symmetry effect (ie J Wolfe & Friedman-Hill 1992). Oblique effects have long been known in visual search (Beck 1972) and texture segregation (Olson and Attneave 1970) and have recently become a renewed focus of investigation in visual search (Prather et al 1995; cf also Westland and Foster 1995; J Wolfe Friedman-Hill Stewart and O'Connell 1992). In the present article we will show that rotating Saarinen's target stimuli so that local orientations are horizontal and vertical is sufficient to make search for local orientation more efficient than for global diagonal targets. We will therefore argue that, rather than global precedence, Saarinen has actually uncovered a rather interesting hierarchical kind of oblique effect in visual search.

Figure 1: Search arrays like those used by Saarinen (1994) to demonstrate global precedence effect. Global, horizontal targets pop out. Local oblique targets are less easily found. In Saarinen's displays target orientation and scale are confounded.

It should be noted that Saarinen attempted to anticipate and refute this kind of interpretation by a control experiment in which global orientation differences were eliminated. He did this by defining his target as a single left-diagonal line amongst right-diagonals, and he demonstrated that search for solitary left-diagonal lines amongst right-diagonals was as efficient as for globally horizontal bars. Evidently, it was not orientation itself that led to slow response, and so this finding lent plausibility to the claim that differences in orientation at a global scale can mask differences in local orientation that would ordinarily be quite salient. However, in Saarinen's control there was no interfering level of information present. The distractors were homogeneous. For this reason, Saarinen's control could not address the possibility that it was the specific orientations used, rather than their scale of presentation, that led to asymmetrical interference in the original experiment. In our Experiment 2 we will offer a control in which targets and distractors are simply made homogenous with respect to the irrelevant scale.

Our control experiment will help to address a second puzzle about the interpretation of Saarinen's data which is that, although there was a 200 msec advantage for the global (horizontal) orientations over the local orientation targets, there was no evidence of an effect of the number of distractors. In other words, both tasks behaved superficially like preattentive pop-out tasks, though the local-target task was notably slower and did not produce the subjective-experience of pop-out (see Figure 1). Saarinen described this as evidence of different time-constants for parallel search, but his control experiment, in light of our oblique interpretation, suggests that it may be perceptual interference that is crucial to delaying response. Our Experiment 2, in which multi-level targets are retained though the irrelevant level is kept homogeneous, will help to show that perceptual interference, not scale per se, is fundamental to differences found in the mixed condition (cf Duncan and Humphreys 1989).

It is important to reiterate that a class 2 oblique effect can, itself, be interpreted as an effect of symmetry about a vertical axis: Symmetry between targets and distractors is known to make visual search less efficient (J Wolfe and Friedman-Hill 1992). This type of oblique effect is to be contrasted with a class 1 oblique effect (Appelle 1972; Essock 1980) which would suggest that the visibility of oblique orientations is inherently diminished. Clear evidence against this latter type of oblique effect in visual search is that it is easier, for example, to find an oblique line amongst verticals than a vertical line among obliques (Treisman and Gormican 1988; see also Foster and Ward 1991). Our experiments were not designed to discriminate between a class 2 oblique effect (confusability of left and right diagonals) and the more general symmetry interpretation, though we will take up further discussion of these issues at the conclusion of our paper.

We will further show that, beyond this class 2 oblique effect, any remaining differences between global and local form detection may be restricted to cases in which visual *search* is irrelevant because only two potential targets are presented.

2 Experiment 1: A new angle

Our primary hypothesis is that Saarinen's rather interesting finding of global precedence in visual search are actually due to effects of the specific orientations used at each scale. To test this possibility we have prepared rotated versions of Saarinen's stimuli so that the local orientations are horizontal or vertical and the global forms are oblique. The result of such a rotation is illustrated in Figure 2. Examination of this figure suggests to us that the pop-out phenomenon now applies to local forms specified by horizontal elements. However, the question of visual search speed cannot be determined by impressions of pop-out. For example, Bridgeman and Aiken (1994; cf also J Wolfe 1992) have shown cases for which pop-out occurs, but search is inefficient (response time is linearly related to the number of distractors) as well as the converse cases where search is quite efficient, but subjective pop-out is not experienced. With rotated stimuli, the relationship between specific orientations and specific scales is reversed. We predict horizontal-orientation precedence which, in the rotated stimuli case, would result in more efficient search for locally-defined targets.

Figure 2: Search arrays from the monitor-tilted condition of Experiment 1. Now it is local, horizontal targets that pop out. Global, oblique targets are harder to find. Rotation of image by 45 degrees will reverse pattern of visibility.

2.1 Method

Our displays were presented on a Viewsonic 17" color monitor [Note 1] which could be mounted on a stand so that the screen was rotated counterclockwise by 45 degrees, as shown in Figure 3. This was done so that our vertical and horizontal line elements could both be diagonal to the path of the raster gun, thus eliminating luminance artifacts normally associated with the asymmetry between vertical and horizontal luminance edges on a CRT [Note 2]. The displays were created and reaction times collected using a Power Macintosh 8100/80 [Note 3]

Figure 3: Illustration of apparatus used to tilt display monitor. Monitor was tilted for half of subjects in Experiment 1 so that local orientation could be cardinal. Physical tilting of monitor was necessary to avoid luminance artifacts of raster monitors (see note 2).

We began by creating a rotated version of Saarinen's (1994) displays in which local target orientation was horizontal and global target orientation was oblique. We refer to this as the *monitor-tilted* condition. Our procedure was otherwise identical to Saarinen's as indicated below. To show that we could replicate Saarinen's results with our displays, we also tested our novel displays in a *monitor-upright* condition so that global orientations were horizontal again. All textures were black on white, and oblique targets were always left-diagonals (45 degrees counterclockwise from vertical).

In the monitor-tilted condition, a rectangular region (oriented with respect to the viewer) of the same visual dimension as the monitor used by Saarinen (20 x 15 deg) was used for the display. Our monitor-upright replication of Saarinen's original condition utilized the same physical display region, rotated back, with the result that the frame of the region was diagonal to the viewer. As will be seen below, this change in the orientation of the frame did not affect our ability to replicate Saarinen's results. We did not mask off the monitor frame in either condition.

Our texture bars were presented on a virtual diagonal grid, comprising 18 positions, as illustrated schematically in Figure 3. Saarinen used a 3 x 6 rectangular grid with a 2.6 deg vertical and horizontal spacing. Our grid is a 45-degree rotation of a rectangular grid, with the boxes repositioned to produce a rectangular bounding window when the monitor is tilted. This is important because it means that our global orientations are aligned with the virtual grid in which targets could appear, as was also true for Saarinen's displays. Our grid spacing was 2.6 degrees along each of the diagonals (ie identical in density to Saarinen's). Our target bars were matched in dimension to Saarinen's, except that they were rotated into oblique and horizontal positions by the positioning of the monitor. Texture positions within the grid were jittered by up to a third of a degree from trial to trial.

Saarinen used three different numerosities of distractor (1, 9, and 17) and two target types (global and local) which he tested in a within-subjects design. We ran two versions of his experiment. In one the local target type was horizontal (monitor-tilted) in the other it was oblique (monitor-upright). We treated the orientation of the monitor as a between-subjects factor in our analysis. Each individual trial was identical in format with those of Saarinen: A brief beep was followed by the presentation of a fixation mark at the center of the display, and after 750 msec, the fixation mark was replaced by the search display until the observer responded by pressing one of two keys to indicate presence or absence of the target. Reaction time was recorded from the onset of the search display and visual feedback was given on each trial. Median response times on correct trials were used for analysis.

The observers were 16 undergraduates at Swarthmore College who were given \$5 and a candy bar for their participation. The data of two additional participants could not be used because of equipment failure or failure to follow instructions.

Eight observers were tested with each monitor orientation. We were concerned that there might be order effects, so half of the observers were tested with global targets first, and half with local targets first. For each type of target, the number of distractors was held fixed for 8 consecutive blocks of 30 trials (half were target-present trials) before changing, consistent with the method reported by Saarinen (1994). The order in which the number of distractors was varied (highest to lowest number or lowest to highest) was crossed factorially with the order in which the tasks (global or local) were performed. In total, each observer performed 720 trials with global targets followed or preceded by 720 trials with local targets. A brief break was given every 30 trials, and a longer break was given

between the first 720 trials and the second 720 trials when the nature of the target changed. The whole procedure took about 1.5 hours.

2.2 Results

Figure 4 shows the average median latencies for both global and local targets separately for the target-present and target-absent trials of each of the two conditions. Mean error rate was 4.2% overall, and there was no evidence of speed-accuracy trade-off. A mixed design $2 \times 2 \times 2 \times 3$ (First Target Type $\times$ Distractor Order $\times$ Target Type $\times$ Distractor Number) repeated measures ANOVA was conducted on medians of each of these four data sets. In our replication of Saarinen's study (monitor-upright condition) search for global, horizontal targets was reliably faster than search for local, oblique targets both in the target-present condition, $F(1,5) = 35.1$, $p < .01$, and in the target absent condition, $F(1,5) = 13.2$, $p < .05$. This is consistent with Saarinen's findings. However, in the tilted monitor condition, this pattern was reversed and the search for local, horizontal targets was marginally faster than for global, oblique targets, in the target-present trials, $F(1,5) = 6.35$, $p = .054$, and reliably faster in the target absent trials, $F(1,5) = 7.1$, $p < .05$.

Figure 4: Results of Experiment 1. Average median reaction times plotted as a function of target type and number of distractors. Separate plots are shown for target-absent and target-present trials for each monitor orientation. Left panels show replication of Saarinen's results. Right panels show evidence of oblique effect from monitor-tilted condition. There were eight observers in each condition. Error bars represent standard errors of the mean. Horizontal grid lines indicate 100 msec intervals.

However, there was a significant interaction such that the influence of the type of local target varied reliably as a function of the number of distractors in the monitor-tilted condition both when the target was present, $F(2,10) = 15.9$, $p < .01$, and when it was absent, $F(2,10) = 7.22$, $p < .05$. As is suggested by visual inspection of Figure 4, this interaction reflects an asymmetry between the two conditions when only a single pair of potential targets was

presented. Because the single distractor (two-stimulus) trials are arguably degenerate search trials, we analyzed these trials separately from the others. When there were only two stimuli to be observed, responses to oblique global targets (537 msec) did not differ reliably from those to horizontal global targets (531 msec), $t(14) = 0.12$, ns, or horizontal local targets (562 msec), $t(7) = 1.03$, ns. On the other hand, response latencies to oblique local targets (792 msec) were reliably greater than to oblique global targets, $t(14) = 3.13$, $p < .01$, as well as to both kinds of horizontal target, $t(14) = 2.74$, $p < .05$ (local), and $t(7) = 5.38$, $p < .01$ (global). The same pattern of asymmetry was evident for the target-absent trials.

Once the single-distractor trials were removed from the analysis, response times to the local, horizontal targets in the monitor-tilted condition were found to be reliably shorter than those to the global, oblique targets. $F(1,7) = 11.1$, $p < .025$.

To test for an overall orientation effect in visual search (on the trials with more than two distractors), we reanalyzed the response times of all observers according to the orientation of the target (horizontal or oblique). A mixed-design $2 \times 2 \times 2$ (Monitor Orientation $\times$ Target Orientation $\times$ Number of Distractors) repeated measures ANOVA on the target-present scores revealed a highly reliable advantage for horizontal targets (495 msec) over oblique targets (625 msec), $F(1,14) = 32.7$, $p < .01$. A global precedence effect would be indicated in such an analysis by an interaction between Target Orientation and Monitor Orientation. However, no such interaction was evident, $F(1,15) < 1.0$. The same pattern of results was found for the target-absent trials.

The same analysis, performed with Target Scale replacing Target Orientation as a factor, revealed no effect of target scale, $F(1,15) < 1.0$. However, there was a highly reliable interaction of Target Scale and Monitor Orientation, $F(1,15) = 33.1$, $p < .01$, again consistent with an oblique effect, but not with a spatial-scale effect.

With regard to the question of whether the search task is affected by the number of distractors, this analysis indicated that search times for the target-present trials were reliably faster with 17 distractors (537 msec) than with only 9 (584 msec), $F(1,14) = 8.88$, $p < .02$. A trend in the same direction in the target-absent trials (694 msec and 779 msec, respectively) was marginally reliable, $F(1,14) = 4.05$, $p = .064$.

2.3 Discussion

Our results support our hypothesis that the apparent advantage of global targets in Saarinen's study was actually a function of orientation. We have found that search times with displays containing multiple potential targets are consistently influenced by the specific orientations of the targets and distractors, rather than by the scale (local or global) at which the target is specified. Although we were able to replicate Saarinen's original findings of apparent global precedence with one version of our displays (monitor upright), the very same displays showed a local precedence effect when the display was rotated by 45 degrees. In other words, precedence was not determined by spatial scale, but simply by spatial orientation (or by the relationships, such as mirror symmetry, between specific orientations). At least for fields of ten or more elements, it appears that diversity of cardinal orientations at either a local or a global scale is sufficient to interfere with the search for an oblique target at the other scale.

The results with two-element displays complicate our account. Unlike the finding with larger numbers of distractors, local differences in cardinal orientation do not appear to have interfered with detecting the presence or absence of globally oblique targets when only two potential targets were presented. This asymmetry of interference (an interaction of scale and orientation) clearly requires explanation. We note that when multiple distractors are present, target presence may be detected as the "odd man out", irrespective of knowing the precise identity of the target. With large numbers of distractors, target localization appears to be done roughly in parallel in the search tasks via a pop-out-like mechanism which was actually speeded by having more distractors. That a different strategy would emerge for two-element displays is unsurprising on this interpretation because "odd-man-out" analysis (eg by non-target grouping, Bacon and Egeth 1991) simply does not apply to a display containing only two elements. Instead, a same/different analysis could apply or serial comparison to an internal standard.

Checking for the presence of an oblique global form among a single pair of potential targets may involve an identification process in which the segmentation of irrelevant local texture differences would be insufficiently salient for low-density displays. For example, the interaction between orientation and target scale may result from greater ease in comparing two largish targets or it may result from a faster serial identification time for large/global forms. In any case, it is clearly arguable that localization processes implied by parallel "visual search" are not necessarily relevant to two-element displays. For this reason, we wish to suggest that the global precedence effect we have identified (following Saarinen) for oblique-target two-element displays is, like Navon's (1977) original findings, an issue of perceptual identification and comparison, not of visual search.

3 Experiment 2: Homogeneous distractors

Saarinen (1994) reported a control experiment in which he used non-hierarchical stimuli, and showed that search for solitary left-diagonal lines among right-diagonals was as efficient as for globally horizontal bars. However, in Saarinen's control, the removal of spatial scale information meant that the distractors were homogeneous by default. This distractor homogeneity is theoretically sufficient to account for efficient search (Callaghan et al 1986; Duncan 1989; Duncan and Humphreys 1989, 1992; Treisman 1991), and the effect is therefore uninformative about the influence of spatial scale. In this experiment we have devised a similar control with homogenous distractors, but retaining both spatial scales to show that spatial scale is irrelevant and that the original effect was due to interference rather than directly reflecting processing speed.

Specifically, in one case (local orientation search) the global structure of the target and distractors would all be homogeneous (ie all vertical or all horizontal). In the other case (global orientation search) all bars (vertical and horizontal) would be identical on the local level (ie all left diagonal or all right-diagonal). Example search displays are shown in Figure 5.

Figure 5: Search arrays from Experiment 2. When distractors are made homogenous, orientation differences pop out at either scale or orientation: Rotation of image by 45 degrees will retain visibility of both targets.

3.1 Method

The displays used were similar to those in Experiment 1 except that the distractors did not differ from the targets at the irrelevant scale. The targets within a block of trials could be one of two targets, as before, but only one kind of distractor was used on each individual trial. On target present trials, the distractor used was identical with the target along the irrelevant dimension.

In order that each orientation type be compared at each scale, each of eight new paid observers performed all four target conditions (ie each scale with both monitor-tilted and monitor upright) so that each orientation (oblique or horizontal) was searched for at each scale by each observer. To accommodate this design, the number of blocks of trials with each number of distractors was reduced from 8 to 4, and observers were allowed to return on two different days to complete the tasks (a different monitor orientation was used on each day). Order of performance of the various tasks was systematically varied across observers. To further alleviate order effects induced by differential practice at the task, the first block of each target type and each number of distractors was not included in the computation of median response time.

3.2 Results and Discussion

Average median response times for each target type and number of distractors are shown in Figure 6. Visual comparison with Figure 4 is facilitated by the grid lines denoting equivalent differences in reaction time. Although differences are present for two-element displays, it is evident that for larger numbers of distractors, the effect demonstrated in Experiment 1 of this paper does not greatly influence a visual search task with uniform distractors (odd man out search). For large numbers of distractors, a $2 \times 2 \times 2$ (Spatial Scale $\times$ Orientation $\times$ Number of Distractors) repeated measures ANOVA, failed to indicate any influence of either orientation, $F(1,7) < 1$, or spatial scale, $F(1,7) < 1$, when the target was present. In other words, in an odd-man-out search task, the detection of the presence of a visually different item can be accomplished with roughly equivalent speed whether the target is defined by local or global orientation and whether the target orientation is oblique or horizontal.

Figure 6: Results of Experiment 2. Average median reaction times plotted as a function of target type and number of distractors. Separate plots are shown for target-absent and target-present trials. There were eight observers. Error bars represent standard errors of the mean. Horizontal grid lines indicate 100 msec intervals.

The data are somewhat different when the target is absent. In this case it appears that observers may have been more rapid to attain certainty of target absence when the target was global ($M = 528$ msec) than when it was local ($M = 557$ msec), $F(1,7) = 4.05$, $p = .084$. This may reflect a subjective sense on the part of the observers that the local targets are more difficult to spot than are the global targets.

As in Experiment 1, the pattern of results with only two items in the display differs from the remainder of the data (and looks quite similar to the results of Experiment 1 with two items). Here, odd-man-out search is not possible, though a same-different judgment would have been adequate. Planned paired-comparisons revealed that response times for the identification of a Local-Oblique target was reliably slower than for that of a Global-Horizontal target. This was true both when the target was present, $t(7) = 2.59$, $p < .05$, and when the target was absent, $t(7) = 3.61$, $p < .01$. No other differences were reliable, though inspection of Figure 6 suggests that both scale and orientation of the target may have affected response time as they did in Experiment 1.

These results make plain that the effects in Experiment 1 resulted from distractor non homogeneity. When the distractors used in a dense field are homogenous, local or global orientation differences of oblique or cardinal orientations are all quite salient. When the distractor elements differ in "irrelevant" orientations, those distractors apparently mask the target if the orientation difference specifying the target concerns oblique lines while that of the distractors is between cardinal orientations.

On the other hand, when only two potential targets appeared in the display, it appears that both the scale and the specific orientations of the targets affect identification or comparison times. Indeed, post-hoc comparisons indicate that responses to local-oblique targets are reliably longer when only a single distractor is presented ($M = 593$ msec) than when 9 ($M = 523$ msec) or 17 ($M = 531$ msec) distractors were present, $t(7) = 4.17$, $p < .025$, and $t(7) = 2.98$, $p < .025$, respectively. The fact that the data for two stimuli differs so markedly from the remainder of the data suggests that a different strategy may be employed by observers on these trials. We propose that these differences should be discussed in terms of visual comparison, not visual search, and we note that disputes about whether these scale effects concern globality or something more akin to absolute size go beyond the scope of this paper (but see Kinchla and J Wolfe 1979).

4 General Discussion

We have shown that Saarinen's (1994) global-precedence account of visual search for hierarchical target stimuli was inadequate. Contrary to the interpretation given by Saarinen, specific orientations appear to be more important in his search paradigm than the specific scale of the target. This may be described a class 2 oblique effect -- the confusability of left and right diagonals, not a difficulty in detecting oblique orientations *per se*.

Oblique effects in search might be attributed to the similarity and confusability of items which are reflections about a vertical axis of symmetry. There are two ways in which symmetry may have played a role. J Wolfe and Friedman-Hill (1992) have demonstrated that distractors which are symmetrical with the target in a visual search task produce greater interference than non symmetrical distractors of the same absolute orientation difference. On the other hand, they have also shown that distractors that are mutually symmetric behave as if they were homogenous and thus speed visual search. Cardinal orientation search in Experiment 1 could have been efficient because of the effective homogeneity of oblique distractors due to their mirror symmetry (J Wolfe and Friedman-Hill 1992). Rotating our displays by 22.5° removes both target-distractor symmetry and distractor-distractor symmetry. This change doesn't appear to make the search task easy at either scale (S Wolfe and Durgin 1997), which is consistent both with the importance of distractor distractor symmetry and with oblique effects (because all lines were oblique).

With reduced search sets of two, we have found size-specific advantages, though we are uncertain whether these require the language of "forest before the trees". Since the time that Navon (1977) published evidence of global precedence in a stroop-like interference task, the nature of the variables underlying Navon's findings have been closely scrutinized. Navon's stimuli were alphanumeric characters composed of smaller alphanumeric characters (cf Kinchla 1974), and it has been suggested that changing the absolute size of the characters (Kinchla and J Wolfe 1979; Lamb and Robertson 1989) or the density of their component elements (Martin 1979) can reverse Navon's global-to-local direction of interference. Ward (1982) has additionally argued for "level readiness" effects in which spatial-scale sensitivity acts as a dynamic perceptual variable. One of the variables that seems to be related to the nature of interference is the visibility of the separate kinds of information, though Hughes et al (1984) have argued that visibility is insufficient in itself to account for differences. Our results (at least those with large set-sizes) may be added to these others as an example of a special kind of perceptual phenomenon that interacts with discriminability in a manner that is orthogonal to the question of hierarchical scale.

Although our experiments were intended to provide a new interpretation of Saarinen's results, we have clearly only scratched the surface of the issues of configuration effects. An excellent review is offered by Kimchi (1994) concerning what might be regarded as configurational information rather than simply hierarchical scale information. Our results emphasize the importance of "nuisance" variables such as specific orientations (cf Saarinen and Levi 1995).

The nature of the information that "pops out" in visual search was once thought to be indicative of visual primitives, such as size and orientation. Recent focus has emphasized the importance of surface shape perception (eg He and Nakayama 1994) and orientation categorization (J Wolfe Friedman-Hill Stewart and O'Connell 1992). The visual search task used in the present paper is quite like a texture segmentation task and it is possible that global-to-local (or middle-out processing, according to Kinchla and J Wolfe 1979) is more evident in the processing of objects rather than textures. However, prior studies of the oblique effect in texture segregation and visual search (in the absence of hierarchically segregated interference) has shown similar oblique effects for textures (Olson and Attneave 1970) and for single element search (Beck 1972). At present we believe that there is little clear evidence for the precedence of "global" information in visual search.

On the other hand, Zelinsky et al (1996) have used eye-movement analyses to try to show that serial visual search may often consist of a global-to-local honing-in process. In their data observers tend to sequentially fixate centers of visual mass closer and closer to the actual target, rather than fixating sequentially, for example, on a series of distractors. The oblique interference effects demonstrated here are consistent with such an account insofar as surface irregularities produced by inhomogeneity at the irrelevant scale mask the visibility of the targets (which are rapidly detectable when the irrelevant information is homogenous). Nonetheless, it is worth noting that a global to local search process as a way of directing attention toward a target could be implemented using information from any visual scale. In other words, the global-to-local division of attended space to which Zelinsky et al appeal is theoretically independent of the question of what spatial scale of visual information is being used to guide search.

In our displays, the search did not become serial in the normal sense as a result of the interfering information. That is, there is no evidence of increased search time with more distractors. But the search process suggested by Zelinsky et al (1996) is a kind of serialized parallel search. In the case of interfering information, it may be that an additional "round" of parallel search is required (cf Friedman-Hill and J Wolfe 1995). That is, the effect of the heterogeneity of cardinal-orientation distractors in Experiment 1 may be to force a second "look" once the more salient but irrelevant differences revealed by the first "look" are processed.

In conclusion, we have shown that visual search for hierarchical targets defined by a specific oblique orientation (at either a local or global scale) can be disrupted by heterogeneity of cardinal orientations among distractors at the other spatial scale. Heterogeneity of oblique orientations does not appear to interfere with search for a cardinal-orientation target. The effect is not one of raw processing speed because it disappears when homogenous distractors are used. Because there is no evidence of serial search in our data, we suggest that this kind of interference effect resembles an attentional Stroop effect (cf Boer and Keuss 1982) in which an initial texture gradient map must be discarded (or compensated for) before the desired gradient map can be accessed. Whatever the process, we have found that the direction of interference in visual search is affected by the specific orientations used, not by their spatial scale.

Footnotes

1. The multisync monitor was set to 832 x 624 pixels (75 Hz refresh) and the image size adjusted to match the display size and resolution used by Saarinen on the built-in Macintosh Plus screen. ([back to text](#))

2. On a normal computer monitor, an ostensibly-white pixel to the immediate right of a black pixel will be about half as luminous as when next to a white pixel. This horizontal non independence is due to the left-to-right scanning of the raster gun illuminating the phosphors on the screen. Vertically adjacent pixels are essentially independent of one another. A left diagonal line and a right diagonal are therefore normally equivalent in luminance, but a vertical black line will affect more ostensibly-white pixels than will a horizontal black line, and so will produce visible differences in local luminance. The safest way to produce equiluminous black vertical and horizontal lines is therefore to draw diagonals on the screen and rotate the monitor itself by 45 degrees. ([back to text](#))

3. Reaction times were recorded to within 3-4 msec accuracy by enforced polling of the keyboard. Relying on the

Apple Event Manager results in reaction time uncertainty of about 17 msec because it only polls the input devices at a frequency of 60 Hz. By controlling the ADB manager directly, one can continuously check for input events on a particular input device, and delays are reduced to 3-4 msec. This is the strategy employed by Dan Costin's KeMo routines available by ftp from ftp.stolaf.edu in the macpsych directory. ([back to text](#))

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Acknowledgments

This research was supported by a Swarthmore College Faculty Research Grant and by the Howard Hughes Medical Institute. We thank Tori Washington for help with the completion of Experiment 2. We are grateful for the comments of Jeremy Wolfe and two anonymous reviewers on an earlier version of this manuscript.

Visual Perception Laboratory **Swarthmore Psychology**

Created by Richa Jain, rjain1@swarthmore.edu