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Relative Judgment Seems to Be the Key: Revisiting the Beck Effect

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In multiple-stimulus presentation, orientation disparity has been known to be more discriminable than disparity in line arrangement (e.g., J. Beck, 1972). The source of the effect and its locus were studied in 7 experiments. In different experiments a discrimination between an upright T and either a tilted T or an L, or a discrimination between a tilted T and an L, was required, either in a single stimulus presentation or in the context of upright Ts. Number of stimuli, location uncertainty, and adjacency between stimuli were manipulated. The results indicated that the effect is insensitive to these factors, which is incommensurate with predictions from several accounts of the effect. All the effect requires is that disparate stimuli are simultaneously presented, suggesting that relative judgment is a necessary condition for its manifestation. The effect surfaces when the task calls for procedures based on perception of homogeneity or salience.

Can stimulus properties be ordered on their perceptibility in a task-invariant manner? For example, would it ever be possible to generalize that a certain color was easier to perceive than a certain spatial frequency or that a given orientation disparity was faster to respond to than a given shape disparity?

The answer seems to be negative, at least for one reason. Stimulus properties that are more effective for texture perception or segregation do not necessarily allow easier discrimination of single stimuli. This conclusion is based on a variety of findings.

For example, disparity of line orientation (as between an upright T and a tilted T) enables easy segregation between groups of elements, whereas differences of the spatial relationships between features (as between an upright T and an upright L) do not (Beck, 1966, 1967; Wolfe, 1992). Likewise, a single tilted T is detected better than a single L when presented on the background of a number of upright Ts (Beck, 1972, 1974; Beck & Ambler, 1972, 1973). However, a tilted T is judged more similar to an upright T than an L is (Beck, 1966), and when the task is to respond to a single stimulus, a tilted T and an L are responded to about equally accurately (e.g., Ambler & Finklea, 1976; Beck, 1972, 1974; Beck & Ambler, 1973).

Those demonstrations of task specificity could be regarded just as evidence that generalizations about attribute perceptibility are hard to come by. But perhaps they might also serve to enlighten us about factors that determine perceptibility. One may start with trying to locate the source of the advantage of line orientation over spatial relationship under the conditions that it is manifested. What actually is the source? We here try to address that issue.

The plan of our article is as follows: We first ask whether the observed task specificity could not be explained away as an artifact of low sensitivity of the test. Once we show that it is not, we proceed to better delineate the conditions under which the advantage of line orientation is manifested.

Test Sensitivity Artifact?

The claim that the advantage of a tilted T over an L surfaces only in arrays of multiple stimuli is based on two types of evidence: One, when presented as single letters, a tilted T is judged more similar to an upright T than an L is. Two, a tilted T has no advantage (in accuracy) over an L when either of them is to be discriminated (in an entire block of trials) from an upright T in a binary discrimination of a single letter.

The former type of evidence might be objected to on the grounds that similarity judgments, being presumably cognitively penetrable (Fodor, 1985; Pylyshyn, 1980), perhaps reflect conceptual biases more than perceptual discriminabilities. But even if they were cognitively opaque, they certainly are based on phenomenal experience. Phenomenal experience might be quite dissociated from the direct effects of perception on our response systems (Watt, 1991).

The latter type of evidence seems to tell us more about perceptual discriminabilities. However, it has previously been observed when the comparison between L and tilted T was done between blocks. Between-blocks manipulation allows the participant to adopt different strategies in different blocks. To examine whether the effect can be demonstrated when the participant cannot anticipate the specific binary discrimination called for in any given trial, we used both L and tilted T as optional alternatives to an upright T in the same block. A failure to observe a difference in a

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disjunctive discrimination task like that would be stronger evidence for the absence of orientation advantage in a single-stimulus presentation.

Furthermore, Beck (1972, 1974; Beck & Ambler, 1972) did not measure reaction time (RT). Accuracy is frequently less sensitive than reaction time is. Accordingly, we measured both.

Suppose our test ascertained that in single-stimulus presentation, a tilted T is not discriminated from an upright T faster than an L is. We would then face the need to specify the conditions for observing an advantage for line orientation and explain the source of that advantage.

Possible Explanations

Several hypotheses about the source of the effect can be discerned in the literature of the recent three decades. Some of the hypotheses have been suggested explicitly. Others seem to be implicit in conventional experimental procedures and typical phrasings.

An old, prominent idea is that the advantage resides in the efficacy of drawing attention toward a disparate stimulus (Beck, 1972). For example, a singleton tilted T may "pop out" on the background of a number of upright Ts, thereby summoning attention to itself (Wolfe, 1994). This *attention-summoning hypothesis* is, of course, a hypothesis about locus, not about mechanism. It does not explain why a singleton L is not as effective in summoning attention as a singleton tilted T is, considering that the former is neither less perceptible from the latter nor less discriminable from an upright T. In addition, it has been demonstrated that an easy-to-detect singleton does not necessarily capture attention (e.g., Folk & Annett, 1994; Hillstrom & Yantis, 1994; Yantis & Egeth, 1994; see Yantis, 1996, for a review). Furthermore, this hypothesis certainly cannot explain why segregation between groups is easier when they differ in line orientation than when the difference is in terms of spatial relationship.

Other possible hypotheses seem more specific about the cause of task specificity. One of them claims that the effect might be due to some high-order property that emerges only when a number of stimuli having the same attribute are presented together, possibly within some constraints on adjacency and spatial layout (e.g., what Beck, 1982, called "hyperfeatures" or "emergent" features for textural perception). For example, what determines the effectiveness of segregation of a tilted T (or a group of tilted Ts) from a group of upright Ts is not orientation per se but rather the configurations of stimuli or component features or topological properties of the group. Let this be called the *group-property hypothesis.*

Alternatively, the preattentive processes that produce segregation might be using statistics like frequency distributions over spatial regions of various types of perceptual elements, of various values of adjacency between elements of the same type, or of local differences along certain dimensions (e.g., Julesz, 1986; Nothdurft, 1985; Sagi & Julesz, 1987). Perhaps the discriminability of fields made up of different stimuli, like an upright T and a tilted T, is due to the differences in such statistics. Those may not necessarily correlate with the differences between the stimuli themselves. Let this be called the *local-statistics hypothesis.*

A somewhat similar account is that preattentive processes might perform some global computations like Fourier analyses (see Julesz & Caelli, 1979), and segregation may capitalize on differences in the products of those computations, like in the power spectra. Again, those differences need not correlate with the differences between the stimuli themselves. Let this be called the *global-computation hypothesis.*

Another explanation resorts to the familiar dichotomy of modes of processing in the mind (e.g., Shiffrin & Schneider, 1977). It is prevalently assumed that processes of field organization that take care of group segregation are preattentive (e.g., Julesz, 1984; Neisser, 1967) or at least done with attention divided across the field (Eriksen & Yeh, 1985; Navon & Pearl, 1985; Rock, Linnet, Grant, & Mack, 1992). Perhaps, then, the effect is due to differences in the efficiency with which different attributes are processed under conditions of focal attention and diffuse attention. For example, line orientation may be easier to process preattentively, or under diffuse attention, but not with focal attention (Beck & Ambler, 1973). Or, more simply, under conditions of focal attention, there are enough resources to process perfectly even the more difficult attribute of spatial relationship (Norman & Bobrow, 1975). Let this be called the *diffuse-attention hypothesis.*

An Alternative Account

The five nonartifactual accounts presented in the last section, especially the latter four ones that focus on cause rather than locus, share two premises: (a) A group of identical stimuli is perceptually different from the sum of the individual stimuli making it up,[1] and (b) the discriminability between two groups (or a single stimulus and a group) is accounted for by the ease with which they may be segregated when presented adjacently.

Either or both of these premises may be wrong or unnecessary. The effect may neither be due to the surplus properties of a group vis a vis its components nor mediated by processes of segregation.

To examine that, we designed most experiments reported below to investigate whether two points can be demonstrated: One, the effect in question will be obtained even when the displays are *not* made up of a single disparate stimulus on the background of a group of stimuli (e.g., a single tilted T on a background of a group of upright Ts), nor of two groups (e.g., a group of tilted Ts adjacent to a group of upright Ts), but rather of two individual stimuli (e.g., a single tilted T adjacent to a single upright T). Two, the effect will also be obtained when segregation is *not* involved, namely when the two groups are already segregated (e.g., by spatial separation). In addition, to test whether the effect

[1] Note that all students of the effect, even if not committed to any of those accounts, used displays with a number of background stimuli.

resides in attentional processes, as the attention-summoning hypothesis posits, we examined the interactions of all factors with the factor of attentional cueing.

If the two premises above were found unnecessary, what could be the necessary condition? We suggest an alternative stated as parsimoniously as can be. Let it be termed the *relative-judgment hypothesis*.

It posits that the process of comparing different stimuli that are simultaneously present, or judging a stimulus in the context of another one(s), is different from the process that tests a single stimulus against two memory representations (schemas, codes, etc.). Whereas the latter involves absolute judgment or identification, the former involves relative judgment or perception of contrasts. It is quite possible that attributes that are not particularly diagnostic for identification, hence are not outstandingly useful for deciding which of two memory representations accommodates the present stimulus better, would still be easy to compare, because the contrast between them would be quite perceptible. For example, line orientation may not be more significant than line arrangement when a single stimulus is processed, yet disparity in orientation may be readily apprehended.

Note that the term *relative judgment* just asserts that processing depends on context, yet is mute with respect to process. It does not necessarily entail, for example, that some emergent properties are considered. Processing of the target letter might just be affected by lateral activation of the features in the context letters. As an analogy, consider the perception of a specific color in the context of another one. Context effects are typically ascribed in that case to the influence of the context color on the perception of the target color rather than to some emergent, higher order properties.

Testing the necessity of relative judgment versus the sufficiency of displaying a group of stimuli is called for. We do that by examining whether or not the effect will be obtained when the display does not allow relative judgment yet consists of a group of identical stimuli.

If relative judgment is shown to be necessary, a further question would be whether it was sufficient for producing the effect. If it were, one upright T would be enough as a context even when the task was to discriminate between an L and a tilted T, since it allows participants to respond to disparities rather than to features of a single stimulus. For that matter, we conducted experiments in which participants were asked to make a discrimination between an L and a tilted T in a context of an upright T, rather than a discrimination between both and an upright T.

Experiment 1

Experiment 1 was designed to provide a more sensitive test for the discriminability advantage of line orientation over spatial relationship in a single-stimulus presentation. For that purpose, we used a discrimination task in which both L and tilted T were optional alternatives to an upright T within the same block, and measured both speed and accuracy of response. As noted above, Beck presented the L and the tilted T in different blocks, a between-blocks manipulation that allows the participant to adopt different strategies in the different blocks, and measured only accuracy, a measure that is often less sensitive than RT. If we failed to observe a difference between the relative discriminabilities of a tilted T and of an L, both in speed and accuracy, in the disjunctive discrimination task used in the present experiment, that would be stronger evidence for the absence of orientation advantage in a single-stimulus presentation.

In addition we used both a single stimulus and a single group of identical stimuli. An absence of orientation advantage when the display does not allow relative judgment, even when it consists of a group of identical stimuli, would imply that presenting a group of stimuli (vs. a single stimulus) is not sufficient for the effect to emerge and that simultaneity of disparate stimuli is necessary.

Method

Participants. Twelve students, 10 women and 2 men aged between 20 and 23, with normal or corrected-to-normal vision, participated in the experiment.

Stimuli. The stimuli were the letters L, upright T, and T tilted 45° clockwise from the vertical. Each letter appeared in a matrix of three possible sizes: 1-letter matrix, 9-letter matrix, and 25-letter matrix. The stimulus matrix appeared with equal frequency in each quadrant of an imaginary square, centered at the fixation point, that subtended 0.49° × 0.49°, 1.63° × 1.63°, or 2.78° × 2.78°, for the 1-, 9-, or 25-letter matrix, respectively. The 1-letter matrix subtended 0.20° × 0.20°, the 9-letter matrix subtended 0.77° × 0.77°, and the 25-letter matrix subtended 1.35° × 1.35°. The center point of the most close-to-fixation letter was located 0.20° of visual angle in a radial line from the central fixation point. Examples of the matrices are presented in Figure 1.

Apparatus. The experiment was controlled by a PDP 11/34 minicomputer, and the stimuli were presented on a VT-11 CRT Graphic Display Unit. The same apparatus was used in all the following experiments.

Design. The task of the participant was to discriminate an upright T from either a tilted T or an L by pressing one of two response keys at each presentation of a stimulus. The experiment used a two-factor repeated-measures design. The factors were

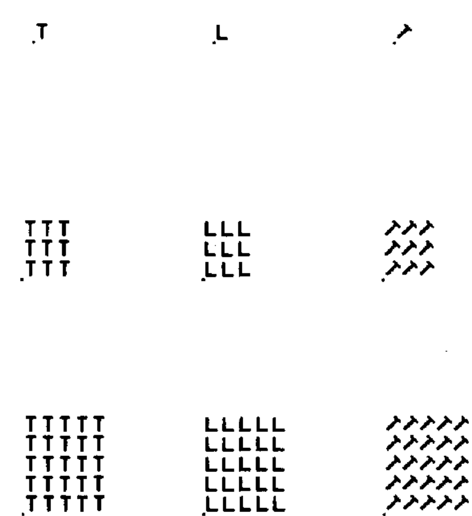

Figure 1. Examples of the stimuli used in Experiment 1.

Letter (upright T, tilted T, and L), and Matrix Size (1-letter, 9-letter, or 25-letter). The different matrix sizes were administered in separate blocks, and their order was counterbalanced across participants. The letters were randomized within blocks, and each letter appeared in equal frequency in each block of trials. Each block included 36 practice trials and 144 experimental trials.

Procedure. Participants sat at a viewing distance of 2 m, with their head resting on a chin rest, and participated individually. The sequence of events for each trial was as follows. First a fixation dot appeared in the center of the field and stayed on till participant responded. The stimulus appeared 500 ms after the appearance of the fixation dot, and stayed on till participant responded or till the 2,500 ms allowed for response had elapsed. Responses were made by pressing one key with one finger of their dominant hand for the presence of an upright T, and another key with another finger for the presence of either a tilted T or an L. We emphasized both speed and accuracy. Half of the participants were instructed to press the right key when an upright T was detected and the left key when a tilted T or an L was detected, and the other half of the participants were given the opposite instructions.

Results and Discussion

Mean RTs for correct responses and percentage errors (PEs) for the three types of stimulus (upright T, L, and tilted T) as a function of matrix size are presented in Table 1. A two-factor (Letter × Matrix Size) repeated-measures analysis of variance (ANOVA), performed on the RT data, indicated no significant effect of letter, $F(2, 22) = 2.23, p > .13$, no significant effect of matrix size, $F(2, 22) = 3.17, p > .06$, and no significant interaction between letter and matrix size, $F(4, 44) = 1.03, p > .40$. Analysis of the error rate data indicated a significant effect of letter, $F(2, 22) = 16.96, p < .0001$, no significant effect of matrix size, $F(2, 22) = 3.10$, $p > .07$, and no significant interaction between letter and matrix size, $F < 1$.

A separate ANOVA for the tilted T and L revealed that responses to these two letters were equally fast (averaged 505 ms and 502 ms, respectively) and equally accurate (averaged 0.81% and 0.98% respectively), $Fs < 1$. The aforementioned effect of letter on accuracy was due to the lower accuracy in responses to the upright T (averaged 4.57%) relative to the accuracy in responses to the tilted T and L.

The results of the present experiment indicate that a tilted T is not discriminated from an upright T faster or more accurately than an L is, even when the tilted T and the L are randomized within block. These results are consistent with the accuracy data reported by Beck (1972, 1974; Beck & Ambler, 1972) for single-stimulus presentation with a between-blocks manipulation. The null effect cannot possibly be due to an artifact of low sensitivity of the test, since we used a within-blocks design and measured both RT and accuracy.

The null effect was also observed when a group of identical letters was presented. That is, no difference between the discriminability of a tilted T and an L was observed when the display did not allow a simultaneous comparison with an upright T, even when it consisted of a group of identical stimuli, rather than a single letter. This finding implies that presentation of a group of stimuli is not sufficient for the manifestation of the orientation advantage effect. Rather, it is seen to suggest that relative judgment may be necessary for its manifestation.

Having ruled out the possibility that the absence of orientation advantage in single-stimulus presentation can be explained away as an artifact of low sensitivity of the test, we proceed with exploring the conditions under which the effect is manifested.

Table 1
Mean RTs and PEs for Each Letter as a Function of Matrix Size in Experiment 1

Matrix size	L		Tilted T		Upright T	
	RT	PE	RT	PE	RT	PE
1	482	1.56	498	1.74	507	4.86
9	502	0.69	490	0.35	524	5.03
25	523	0.69	528	0.35	547	3.82

Note. RT = reaction time; PE = percentage error.

Experiment 2

The purpose of Experiment 2 was threefold: first, to examine whether the advantage of line orientation over line arrangement is also obtained when segregation is not involved; second, to examine whether the number of elements in the display has an effect on the relative advantage of line orientation; and third, to examine whether the orientation advantage effect resides in attentional processes.

The participants in this experiment were required to detect the presence of a disparate matrix of either tilted Ts or Ls on the background of three matrices of upright Ts. The matrices appeared either adjacent to each other or spatially separated, so that presumably no segregation was involved in the latter. In addition, we used an attentional cueing manipulation. Participants performed the task of detecting disparity in a cue condition or in a no-cue condition. In the cue condition, a cue indicating the location of the disparate matrix of letters preceded the presentation of the stimulus. No such cue was presented in the no-cue condition. If the orientation advantage effect resides in attentional processes, as the attention-summoning hypothesis suggests, then the effect is expected to vanish or to be reduced in the cue condition relative to the no-cue condition. Both RT and accuracy were measured.

Method

Participants. Eight students at the University of Haifa, 4 women and 4 men aged between 20 and 25 participated in this experiment. All participants had normal or corrected-to-normal vision. None had participated in the previous experiment.

Stimuli. The stimuli were quadruplets of matrices of letters. The possible letters were L, upright T, and tilted T. The four matrices formed an imaginary square. The number of letters in a matrix was 1 or 9. There were three types of stimuli: (a) all the four matrices were composed of upright Ts; (b) three matrices were composed of upright Ts, and one matrix was composed of Ls; and (c) three matrices were composed of upright Ts, and one matrix was composed of tilted Ts. The disparate matrix appeared in each of the four positions with equal frequency. The matrices appeared either adjacent to each other or spatially separated. Participants sat 2 m from the screen. From this position the elemental letter subtended 0.20° of visual angle. The center point of the most close-to-fixation letter of each matrix was located 0.20° of visual angle in a radial line from the central fixation point in the adjacent matrices condition, and 1° in the separated matrices condition. A field of adjacent matrices subtended 0.49° × 0.49° and 1.63° × 1.63°, for 1- and 9-letter matrices, respectively, and a field of separated matrices subtended 1.60° × 1.60° and 2.75° × 2.75°, for 1- and 9-letter matrices, respectively. The cue indicator was a black dot that subtended 0.15° and was placed at the quadrant of the disparate matrix, 0.39° in a radial line from the fixation point in the adjacent condition, and 1.18° in the separated matrices condition. Examples of the stimuli are presented in Figure 2.

Design. The participant's task was to detect the presence of a disparate matrix in the stimulus quadruplet. The experiment used a completely crossed repeated-measures four-factor design: Stimulus Type (all upright Ts, a disparate matrix of Ls, a disparate matrix of tilted Ts), Adjacency (adjacent or separated), Matrix Size (1 or 9), and Cueing Condition (cue or no cue). Each stimulus type and adjacency condition appeared randomly and with equal frequency in each block of trials. Participants performed the task with each matrix size in two cueing conditions. In the cue condition, a cue indicating the location (i.e., the quadrant) of the disparate matrix was given. The cue appeared both in the positive trials (disparity present) and in the negative trials (disparity absent), and it was completely valid in the positive trials. In the no-cue condition, no cue was presented. The four combinations of cueing condition and matrix size were administered in four separate blocks, and their order was counterbalanced across participants. Each block included 48 practice trials and 192 experimental trials.

Procedure. The sequence of events for each trial was as follows. First a fixation dot appeared at the center of the field and stayed on till the participant responded. The stimulus appeared 500 ms after the appearance of the fixation dot and stayed on till the participant responded or till the 2,500 ms allowed for response had elapsed. When a cue was given, it appeared 400 ms after the appearance of the fixation dot for 100 ms. At the start of each block, participants were instructed about the nature of the task and were familiarized with the stimuli. In the cue condition, participants were informed about the cue and were told that whenever a disparate stimulus will be present in the display, it will appear in the quadrant indicated by the cue. Responses were made by pressing one key with one finger of their dominant hand for the presence of a disparate matrix, and another key with another finger for the absence of a disparate matrix. We emphasized both speed and accuracy. Half of the participants were instructed to press the right key when a disparate matrix was detected and the left key when no

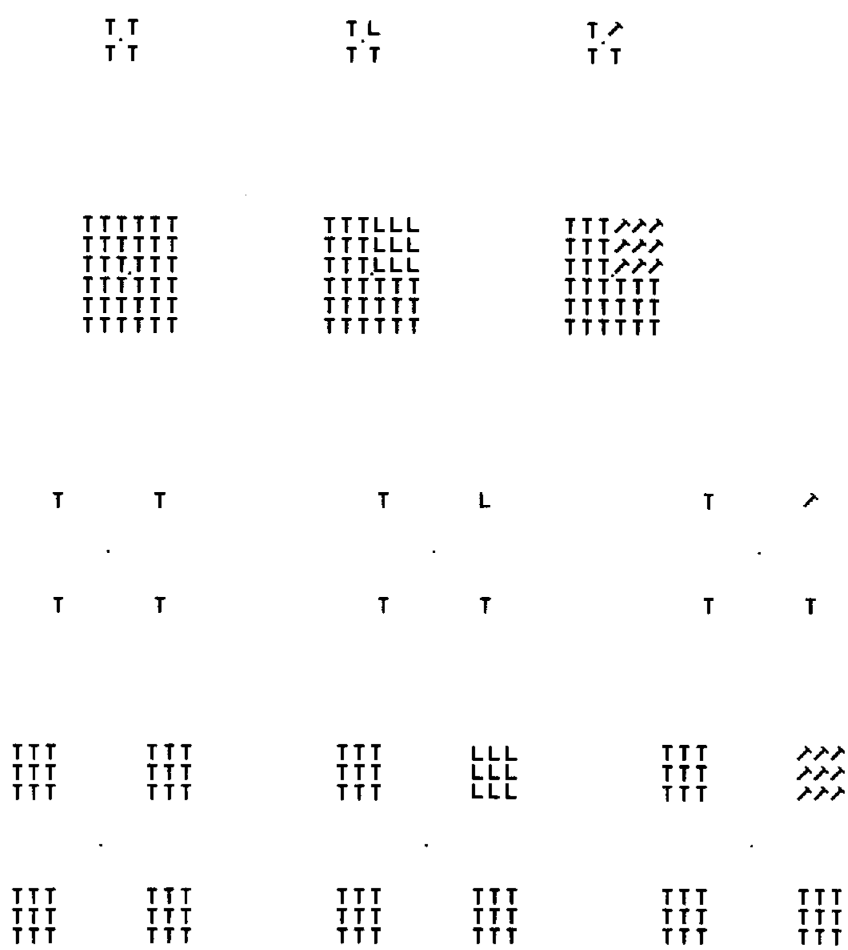

Figure 2. Examples of the stimuli used in Experiments 2 and 3 for the adjacent (top) and the spatially separated (bottom) conditions.

disparate matrix was detected, and the other half of the participants were given the opposite instructions.

Results and Discussion

Mean RTs for correct responses and PEs for the three types of stimulus as a function of matrix size, adjacency, and cueing conditions are presented in Table 2.

An overall four-factor (Cueing × Stimulus × Matrix Size × Adjacency) repeated-measures ANOVA, performed on the RT data, indicated a significant effect of stimulus, $F(2, 14) = 8.80, p < .004$, a significant effect of adjacency, $F(1, 7) = 18.39, p < .005$, a significant interaction between stimulus and matrix size, $F(2, 14) = 7.65, p < .01$, and a significant interaction between adjacency and cueing, $F(1, 7) = 6.46, p < .05$. There was no main effect of cueing, $F < 1$, and no interaction between cueing and stimulus, $F < 1$. Analysis of the error-rate data indicated a significant effect of cueing, $F(1, 7) = 8.79, p < .025$, that interacted with stimulus, $F(2, 14) = 6.57, p < .01$.

We conducted further analyses separately for the positive trials (i.e., trials with a disparate matrix) and for the negative trials (all upright Ts). The four-factor (Cueing × Stimulus × Matrix Size × Adjacency) repeated-measures ANOVA for the positive trials indicated that the detection of a disparate matrix of tilted Ts (averaged 570 ms) was significantly faster than the detection of a disparate matrix of Ls (averaged 623 ms), $F(1, 7) = 31.06, p < .0008$. The speed advantage of tilted Ts was larger for 9-letter matrix (averaged 85 ms) than for 1-letter matrix (averaged 21 ms), as indicated by the significant interaction between matrix size and stimulus, $F(1, 7) = 9.75, p < .02$, but in examining simple effects it was found significant for both sizes, $F(1, 7) = 12.92, p < .01$, $F(1, 7) = 20.13, p < .005$, for 1- and 9-letter matrix, respectively. The increase in the relative advantage of tilted T with the increase in matrix size was due mainly to an increase in RT to the disparate matrix of L. RTs to adjacent matrices (averaged 588 ms) were significantly faster than RTs to separated matrices (averaged 604 ms), $F(1, 7) = 7.70, p < .05$. No significant interaction involving the adjacency factor was found. Advance cueing of the location of the disparate matrix had no effect on the speed of detecting it, ($F < 1$), and there was no significant interaction involving the cueing factor.

An identical ANOVA performed on the error-rate data indicated a significant interaction among stimulus type, matrix size, and adjacency, $F(1, 7) = 16.00, p < .01$. Stimulus type interacted significantly with matrix size in the adjacent matrices condition, $F(1, 7) = 31.50, p < .0008$, but not in the separated matrices condition, $F(1, 7) = 1.00, p > .35$. Error rate in detecting a disparate matrix with adjacent 1-letter matrices tended to be higher for tilted T (1.56%) than for L (0.78%), whereas the opposite trend was observed with adjacent 9-letter matrices (0.20% and 1.76%, for tilted T and L, respectively). No other main effect or interaction was significant.

The ANOVAs performed on the RT and the PE data for the negative trials revealed a significant effect of adjacency, $F(1, 7) = 13.42, p < .008$, a significant interaction between adjacency and cueing, $F(1, 7) = 6.79, p < .05$, and a significant interaction among adjacency, cueing, and matrix size, $F(1, 7) = 8.55, p < .025$, for RT, and a significant effect of cueing, $F(1, 7) = 11.82, p < .02$, for PE. RTs in the cue condition were slower than RTs in the no-cue condition, except for the separated 9-letter matrices, and participants committed a higher PE in the cue condition (3.91%) than in the no-cue condition (1.17%), presumably because of the invalidity of the cue in the negative trials.

The results of the present experiment clearly show that orientation disparity (i.e., a tilted T vs. an upright T) is detected faster and often more accurately than disparity in line arrangement (i.e., an L vs. an upright T). These results are consistent with Beck's data obtained in texture segregation and grouping (Beck, 1966, 1967), and in a detection of disparity task with a single disparate stimulus (Beck, 1972, 1974; Beck & Ambler, 1972, 1973). The present findings extend these previous ones by obtaining the advantage effect (a) under randomization of the disparate letters within blocks and (b) in a detection of disparity task with groups of letters as well as with single letters. The effect increased with

Table 2
Mean RTs and PEs for the Three Types of Stimuli as a Function of Adjacency and Matrix Size Under the Two Attention Conditions in Experiment 2

	Adjacent						Separated					
	L		Tilted T		Upright T		L		Tilted T		Upright T	
Matrix size	RT	PE	RT	PE	RT	PE	RT	PE	RT	PE	RT	PE
						Cue						
1	620	0.78	605	1.56	625	3.91	632	1.56	621	1.95	633	3.91
9	643	2.34	556	0.39	661	3.91	630	1.56	558	1.95	657	3.91
						No cue						
1	579	0.78	549	1.56	568	0.78	597	1.95	571	0.39	581	0.78
9	616	1.17	538	0.00	630	1.17	663	0.39	559	0.39	705	1.95

Note. RT = reaction time; PE = percentage error. The three types of stimuli are (a) a disparate matrix of L, (b) a disparate matrix of tilted T, and (c) no disparate matrix (all upright Ts).

an increase in number of elements in the stimuli, but it was significant both for 1-letter and 9-letter matrices.

The orientation advantage effect was present both for adjacent and spatially separated stimuli, suggesting that need for segregation is not necessary for the manifestation of the effect.

The effect was present even when the location of the disparate stimulus was cued in advance, that is, when attention was presumably focused on the disparate stimulus. This null effect of cueing[2] suggests that the orientation advantage does not reside in attentional processes such as summoning or shifting attention, as the attention-summoning hypothesis assumes.

This finding also seems to argue against the diffuse-attention hypothesis that suggests that under conditions of diffuse attention there are enough resources to process differences in line orientation but not in line arrangement, whereas under conditions of focal attention there are enough resources to process the latter as well (Beck & Ambler, 1973). Of course, there is a sense in which focusing of attention may be pertinent. If focusing attention not only increases the availability of resources but also denies access to output of any processing of the simultaneously presented stimuli that does not require attention, then it becomes functionally similar to a single-stimulus presentation. In such a condition the effect is not manifested, as indicated by the results of Experiment 1. Thus, access to output of preattentive processing of the simultaneously presented stimuli may be necessary, but modulation in visual attention—which the diffuse-attention hypothesis is all about—may be immaterial.

Contrary to our results, Beck and Ambler (1973) found that the discriminability advantage of line orientation (measured by accuracy) vanished when their participants received an indicator of the location of the disparate figure. This discrepancy might be attributed to a difference in presentation conditions. In the experiment of Beck and Ambler, the display was briefly presented and masked after a short delay, whereas in the present experiment, there was no masking and the display stayed on until the participant responded. How could that have produced the discrepancy in the results? One conceivable mediating variable is spread of visual attention. It has been suggested that the "beam" of visual attention can assume different values of spread, much like a zoom lens, and it has been demonstrated that performance is sensitive to that spread (see, e.g., Eriksen and St. James, 1986). It is quite possible that under masked short exposure, the spread would be narrow, lest processing would be gravely hindered. That might not be necessary under unmasked unlimited exposure. If indeed attention in Beck and Ambler's experiment was narrowly focused to the degree that access to output of any processing of the simultaneously presented stimuli was obviated, then the task would be restricted to identifying the target in the cued location, much like it is done in a single-stimulus presentation. That might not have happened, however, in our experiment in which the spread of attention could be sufficient to encompass the context characters as well.

Alternatively, the discrepancy might be due to a differential effect of presentation conditions on spatial resolution. The argument resorts to the combination of two findings. First, it has been shown that exposure duration interacts with eccentricity in its effect on orientation discrimination, so that high eccentricity improves orientation discrimination relative to central retinal locations under masked short exposure, but not under unmasked unlimited exposure (e.g., Gurnsey, Pearson, & Day, 1996; Kehrer, 1989). It is assumed that performance drops toward the center because spatial resolution is too high for this kind of discrimination (e.g., Gurnsey et al., 1996). Second, Yeshurun and Carrasco (1998) recently demonstrated that, under masked short exposure, cueing impaired orientation discrimination at central retinal locations and improved it in the far periphery. Their account of these findings is that cueing enhances spatial resolution. Now, if spatial resolution is involved both in the effect of eccentricity and in the effect of cueing, then it is possible that the effect of cueing on spatial resolution interacts with exposure duration in the same way that eccentricity interacts with it. If so, masked short exposure (as used by Beck & Ambler, 1973) would enable cueing to enhance spatial resolution, thereby nullifying any orientation advantage, whereas under unmasked unlimited exposure (as we used), cueing would not necessarily enhance spatial resolution, hence orientation advantage would be unaffected.

Experiment 3a

The results of Experiment 2 showed that the orientation advantage effect interacted with matrix size, even though the effect was significant for both sizes used. Experiment 3 was designed to study more systematically the effect of number of elements, both for adjacent and spatially separated stimuli. Three matrix sizes, 1-letter, 4-letter, and 25-letter matrices, were used. In Experiment 3a the manipulation was blocked. In Experiment 3b it was randomized within blocks.

Method

Participants. Twelve students, 10 women and 2 men aged between 20 and 31 participated in the experiment. All participants had normal or corrected-to-normal vision. None had participated in the previous experiments.

Stimuli. The stimuli were identical to the ones used in Experiment 2, except that the number of letters in a matrix was 1, 4, or 25. A field of adjacent matrices subtended 0.49° × 49°, 1.06° × 1.06°, and 2.78° × 2.78°, for 1-, 4-, and 25-letter matrices, respectively, and a field of separated matrices subtended 1.60° × 1.60°, 2.18° × 2.18°, and 3.89° × 3.89°, for 1-, 4-, and 25-letter matrices, respectively.

Design and procedure. The design and procedure of the present experiment were identical to those of the no-cue condition in Experiment 2. Participants performed the task of detection of disparity with the three matrix sizes in separate blocks, and their order was counterbalanced across participants. Each block included 48 practice trials and 240 experimental trials.

[2] We have replicated this finding both when the cue was presented for a longer duration (150 ms) and when a central arrow was used as a cue.

Results

Mean RTs and PEs for the three stimulus types as a function of adjacency and matrix size are presented in Table 3.

All main effects and interactions were significant in an overall three-factor (Stimulus × Matrix Size × Adjacency) repeated-measures ANOVA for the RT data. For the three stimuli, RT was faster for adjacent than for separated matrices, $F(1, 11) = 36.32$, $p < .0001$, and the effect of adjacency increased with the increase in matrix size, as indicated by the significant interaction between matrix size and adjacency, $F(2, 22) = 21.74$, $p < .0001$. The significant effect of matrix size, $F(2, 22) = 22.24$, $p < .0001$, was qualified by a significant interaction between matrix size and stimulus, $F(4, 44) = 12.55$, $p < .0001$: RT increased with an increase in matrix size for the no-disparity stimulus and for the L, but not for the tilted T. An ANOVA for the error-rate data indicated a significant effect of stimulus, $F(2, 22) = 4.64$, $p < .025$, with the higher PEs observed in the negative trials.

The three-factor (Stimulus × Matrix Size × Adjacency) ANOVAs for the positive trials showed that a disparate matrix of tilted Ts was detected significantly faster and more accurately (averaged 589 ms, 1.11% error) than a disparate matrix of Ls (averaged 670 ms, 2.88% error), $F(1, 11) = 60.40$, $p < .0001$, $F(1, 11) = 8.10$, $p < .02$, for RT and PE, respectively. The relative speed advantage of tilted T increased with an increase in matrix size (30, 80, and 132 ms, for 1-, 4-, and 25-letter matrix, respectively), as indicated by the significant interaction between matrix size and stimulus, $F(2, 22) = 21.81$, $p < .0001$. The effect, however, was significant for all matrix sizes, $F(1, 11) = 13.68$, $p < .005$, $F(1, 11) = 29.53$, $p < .002$, $F(1, 11) = 61.96$, $p < .0001$, for 1-, 4-, and 25-letter matrix, respectively.

Experiment 3b

Method

Participants. Six students, 3 women and 3 men aged between 20 and 26 with normal or corrected-to-normal vision participated in the experiment. None had participated in the previous experiments.

Stimuli. The stimuli were identical to the ones used in Experiment 3a.

Design and procedure. The factor of matrix size was randomized within block. The experiment consisted of one block of 864 experimental trials, preceded by 72 practice trials. All the other aspects of the design and the procedure were identical to those of Experiment 3a.

Results

Mean RTs and PEs for each stimulus type as a function of matrix size and adjacency are presented in Table 4.

An overall three-factor (Stimulus × Matrix Size × Adjacency) repeated-measures ANOVA, performed on the RT data, indicated a significant effect of stimulus, $F(2, 10) = 14.57$, $p < .0015$. RT was faster for adjacent than for separated matrices, $F(1, 5) = 47.54$, $p < .001$, but the effect of adjacency was larger for the upright T and L than for the tilted T, as indicated by the significant interaction between adjacency and stimulus, $F(2, 10) = 5.41$, $p < .05$, and it increased with an increase in matrix size, as indicated by the significant interaction between matrix size and adjacency, $F(2, 10) = 16.96$, $p < .0006$. The significant effect of matrix size, $F(2, 10) = 11.54$, $p < .0025$, was qualified by a significant interaction between matrix size and stimulus, $F(2, 10) = 6.20$, $p < .0025$: RT increased with an increase in matrix size for the upright T and L, but not for the tilted T. Error rates showed similar effects to those of the RT data, but none of the effects was significant.

A three-factor (Stimulus × Matrix Size × Adjacency) repeated-measures ANOVA for the positive trials indicated that a disparate matrix of tilted Ts was detected significantly faster (averaged 645 ms) than a disparate matrix of Ls (averaged 736 ms), $F(1, 5) = 28.17$, $p < .005$. This effect was larger for larger matrices (23, 93, and 160 ms, for 1-, 4-, and 25-letter matrices, respectively), as indicated by the significant interaction between matrix size and stimulus, $F(2, 10) = 17.23$, $p < .0006$, and larger for separated matrices (122 ms) than for adjacent matrices (62), as indicated by the significant interaction between stimulus and adjacency, $F(1, 5) = 7.51$, $p < .05$.

Discussion

The results of Experiment 3 replicated those of Experiment 2. The orientation advantage effect increased with an increase in the number of the stimuli, but it was significant in all matrix sizes. This increase was due more to an increase in

Table 3
Mean RTs and PEs for the Three Types of Stimuli as a Function of Adjacency and Matrix Size in Experiment 3a

Matrix size	Adjacent						Separated					
	L		Tilted T		Upright T		L		Tilted T		Upright T	
	RT	PE	RT	PE	RT	PE	RT	PE	RT	PE	RT	PE
1	618	2.50	586	1.88	627	4.17	623	2.08	595	1.46	633	5.42
4	638	2.29	563	1.04	627	3.96	674	2.91	590	0.21	697	5.21
25	701	4.38	590	1.25	683	2.71	766	3.13	612	0.83	798	4.58

Note. RT = reaction time; PE = percentage error.

Table 4
Mean RTs and PEs for the Three Types of Stimuli as a Function of Adjacency and Matrix Size in Experiment 3b

Matrix size	Adjacent						Separated					
	L		Tilted T		Upright T		L		Tilted T		Upright T	
	RT	PE	RT	PE	RT	PE	RT	PE	RT	PE	RT	PE
1	626	1.39	617	2.43	662	5.21	697	2.08	661	2.08	749	4.17
4	637	0.69	581	1.04	668	4.51	788	1.04	659	1.39	901	3.82
25	731	1.74	611	0.35	770	3.82	939	4.86	738	1.39	983	1.74

Note. RT = reaction time; PE = percentage error.

RT to the disparate L than to a decrease in RT to the disparate tilted T. This finding is consistent with the one reported by Ambler, Keel, and Phelps (1978), with a between-blocks manipulation of the discrimination task. They found an increase in RT when the number of letters was increased from 1 to 4 for a discrimination between an upright T and an L, but not for a discrimination between an upright T and a tilted T.

As in Experiment 2, the orientation advantage effect was observed under both adjacency conditions.

Experiment 4

In Experiments 2 and 3 adjacency and eccentricity were necessarily confounded because the spatially separated stimuli were presented (necessarily) more peripherally than the adjacent stimuli. Experiment 4 was designed to test directly the independent effect of retinal location by presenting the stimulus at the center of the field and at two locations away from the center, while holding adjacency constant.

Method

Participants. Eight students, 5 women and 3 men aged between 20 and 26 with normal or corrected-to-normal vision participated in the experiment. None had participated in the previous experiments.

Stimuli. The stimuli were quadruplets of adjacent 1-letter matrices (or, to put it differently, each stimulus was a four-element matrix). The stimulus appeared equally often at any of three retinal locations: centered at the center of the field, at a distance of 20 mm from the center of the field, or at a distance of 40 mm from the center of the field. When presented off center, the stimulus appeared with equal frequency in each of the corners of an imaginary square that subtended 1.30° × 1.30° in the close off-center location, and 2.10° × 2.10° in the far off-center location (see Figure 3).

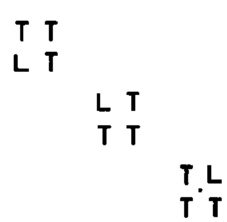

Figure 3. Examples of the stimuli used in Experiment 4.

Design and procedure. Stimulus type and eccentricity were randomized within block. The experiment included 36 practice trials and 576 experimental trials. All other aspects of the procedure and the design were identical to those of Experiment 2 (no-cue condition).

Results and Discussion

Mean RTs and PEs for each stimulus type as a function of eccentricity are presented in Table 5.

An overall two-factor repeated-measures ANOVA (Retinal Location × Stimulus) for the RT data indicated a significant effect of location, $F(1, 7) = 8.84, p < .005$, and a significant effect of stimulus, $F(2, 14) = 5.97, p < .015$. The interaction between retinal location and stimulus was not significant, $F < 1$. The analysis of the error data showed a significantly higher error rate for the negative trials than for the positive trials, $F(2, 14) = 5.76, p < .015$.

ANOVAs for the positive trials indicated a significant effect of location, $F(2, 14) = 4.32, p < .05$, and a significant effect of stimulus, $F(1, 7) = 14.66, p < .01$, for RTs only. The interaction between retinal location and stimulus was not significant, $F < 1$. Post hoc comparisons using Duncan procedure revealed that RTs to stimuli presented at the center of the visual field and at the closer off-center location were significantly faster than RTs to stimuli presented at the far off-center location.

The results of the present experiment indicated that the general speed of discrimination decreased with eccentricity, but the relative discriminability of a tilted T and of an L was not affected by retinal location.

Experiment 5

The results of Experiment 1 on the one hand, and those of Experiments 2–4 on the other hand, seem to suggest that simultaneous presentation of upright Ts is a necessary condition for the manifestation of the discriminability advantage of a tilted T over an L. Note, however, that the difference between Experiment 1 and Experiments 2–4 was not only in the simultaneity of the stimuli but also in the instructions: Participants in Experiment 1 were instructed explicitly to discriminate between an upright T and either a tilted T or an L, whereas participants in Experiments 2–4 were instructed to detect the presence of a disparate stimulus.

Experiment 5 attempted to rule out the possibility that the

Table 5
Mean RTs and PEs for the Three Types of Stimuli as a Function of Retinal Location in Experiment 4

Retinal location	L		Tilted T		Upright T	
	RT	PE	RT	PE	RT	PE
Center	605	1.37	588	1.17	606	2.34
Close	614	0.78	597	0.59	624	3.32
Far	629	1.37	608	1.37	652	4.30

Note. RT = reaction time; PE = percentage error.

difference between the results of Experiments 2–4 and those of Experiment 1 is due to different instructions, rather than to the presence–absence of upright Ts. Participants in this experiment received exactly the same instructions as those of Experiment 1. Namely, they were required to discriminate an upright T from either a tilted T or an L, but a context of an upright T (or a matrix of upright Ts) was always simultaneously present. In addition, spatial certainty with respect to the appearance of the target stimulus was manipulated.

If the orientation advantage effect was observed in this experiment, it would rule out the possibility that the null effect observed in Experiment 1 can be explained away as an artifact of task instructions. Furthermore, if the effect was observed with a minimal context of one letter, it would provide evidence that not only is presenting a group of stimuli not a sufficient condition for the effect (as indicated by the results of Experiment 1) but also that it is not a necessary condition for its manifestation.

Method

Participants. Twelve students, 9 women and 3 men aged between 20 and 26, with normal or corrected-to-normal vision, participated in the experiment. None had participated in the previous experiments.

Stimuli. The target stimuli were an upright T, a tilted T, and an L. Each stimulus appeared in a matrix of three possible sizes: 1-letter matrix, 9-letter matrix, and 25-letter matrix. In addition, one matrix of upright Ts was also present on each trial and served as a context stimulus. The size of the context matrix was always identical to that of the target matrix. Thus, there were three types of display: One contained two matrices of upright Ts, one contained a matrix of tilted Ts and a matrix of upright Ts, and one contained a matrix of Ls and a matrix of upright Ts. There were two different presentation conditions defined by the spatial location of the stimuli. In the central condition, the target matrix appeared always at fixation, and the context matrix appeared randomly either to its right or to its left side. In the noncentral condition the target matrix appeared 0.20° of visual angle to the right or to the left of fixation, in a random fashion, and the context matrix appeared 0.20° to the other side of the fixation point. Examples of the stimuli in the two spatial conditions are presented in Figure 4.

Design and procedure. The task of the participant was to discriminate an upright T from either a tilted T or an L by pressing on one of two response keys at each presentation of a stimulus. The experiment used a three-factor repeated-measures design: Stimulus (T, tilted T, and L), Matrix Size (1-letter, 9-letter, or 25-letter matrices), and Spatial Position (central or noncentral). The different matrix sizes were administered in separate blocks for each spatial condition. The order of the spatial conditions as well as the order of the matrix sizes were counterbalanced across participants. The letters were randomized within blocks. Each block included 24

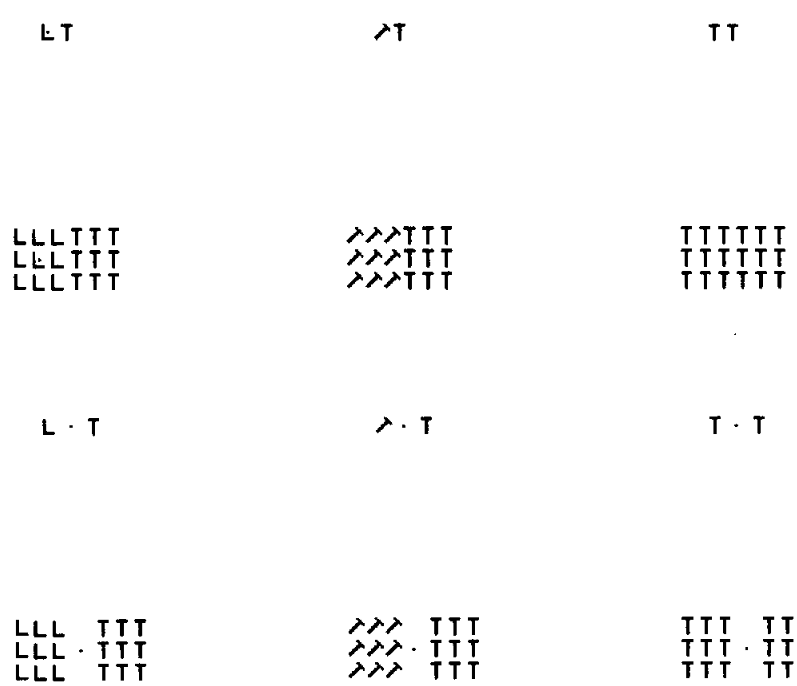

Figure 4. Examples of the stimuli used in Experiments 5 and 6 for the central (top) and the noncentral (bottom) presentation conditions. Only the stimuli with the Ls and the tilted Ts were used in Experiment 6.

practice trials and 120 experimental trials. All other aspects of the procedure were identical to those of Experiment 1.

Results and Discussion

Mean RTs and PEs for the three letters as a function of matrix size and spatial position are presented in Table 6.

Three-factor repeated-measures ANOVAs (Stimulus × Matrix Size × Spatial Position), conducted on the RT and the PE data, indicated a significant effect of stimulus, $F(2, 22) = 10.70, p < .0006$, $F(2, 22) = 20.77, p < .0001$, for RT and PE, respectively, and a significant effect of size for RT only, $F(2, 22) = 7.17, p < .004$. The interaction between stimulus and matrix size was significant for PE only, $F(4, 44) = 2.78, p < .05$: Error rate in responding to a tilted T or an L tended to be higher for the multielement matrices than for one-letter matrices, whereas the opposite trend was observed in responding to an upright T (see Table 6).

A separate ANOVA for the tilted T and L revealed that responses to the tilted T were significantly faster than responses to the L (averaged 467 ms and 486 ms, for tilted T and L, respectively), $F(1, 11) = 11.30, p < .01$, and more accurate (averaged 1.94% and 3.05%, for tilted T and L, respectively), $F(1, 11) = 7.18, p < .025$. The difference in RTs between the tilted T and the L tended to increase with an increase in matrix size, but it was observed for all matrix sizes at both spatial positions, except for one-letter matrices in the noncentral presentation, as indicated by the significant interaction among stimulus, size, and spatial position, $F(2, 22) = 3.64, p < .05$. No interaction effects were found for accuracy.

These results clearly show that the discrimination between an upright T and either a tilted T or an L (i.e., the same task as in Experiment 1), when performed in a context of an upright T, yielded the same relative advantage of a tilted T over an L as in the detection of disparity task (Experiments 2–4). The effect was observed in both conditions of spatial position, suggesting that the effect was insensitive to spatial certainty with respect to the location of the target stimuli (certainty in the central presentation condition vs. uncertainty in the noncentral presentation condition), and to adjacency between the target stimulus and the context stimulus (adjacent in the central presentation condition vs. separated in the noncentral presentation condition). Notwithstanding the case of one-letter matrix in the noncentral presentation, a context of one upright T, and clearly of one matrix of upright Ts, was sufficient to produce the effect.

The present results rule out the possibility that the presence of the orientation advantage effect in Experiments 2–4 and its absence in Experiment 1 was due to the different instructions. Rather, they provide converging evidence for the necessity of simultaneous presentation of an upright T for the emergence of the effect. When an upright T was not simultaneously present the effect was not observed, as indicated by the null effect in Experiment 1; when it was simultaneously present, the effect was observed (Experiments 2–5).

Experiment 6

Taken together the findings of Experiments 1–5 are seen to suggest that relative judgment is a necessary condition for the manifestation of the orientation advantage effect. Presenting a group of stimuli, on the other hand, is neither a sufficient (Experiment 1) nor a necessary (Experiment 5) condition for the manifestation of the effect. The following experiment addresses a further issue: Is relative judgment a sufficient condition as well?

As seen in the results of Experiment 5, a context of one upright T was sufficient to give rise to the orientation advantage effect when the task called for discriminating an upright T from either a tilted T or an L. However, if such a context was generally sufficient, it would also give rise to an orientation advantage effect when the task is a simple binary discrimination between T and L. It has been demonstrated that without the context of an upright T, the stimuli L and tilted T are responded to in the same manner (e.g., Experiment 1). If a context of one upright T acted to generate some effect on RT, then it must be because the context allowed participants to respond to disparities rather than to features of a single stimulus. If however, one upright T (or one matrix of upright Ts) was insufficient to generate the effect in a task of simple binary discrimination, then the question would be whether it is possible to find another condition that, when conjoined with relative judgment, would be sufficient to generate the effect.

Method

Participants. Twelve students from the University of Haifa, 6 women and 6 men aged between 23 and 27 years, participated in the experiment for course credit. All had normal vision. None had participated in the previous experiments.

Table 6
Mean RTs and PEs for Each Letter as a Function of Matrix Size Under the Two Spatial Presentation Conditions in Experiment 5

Matrix size	Central position						Noncentral position					
	L		Tilted T		Upright T		L		Tilted T		Upright T	
	RT	PE	RT	PE	RT	PE	RT	PE	RT	PE	RT	PE
1	467	2.91	455	1.88	489	11.04	449	2.50	451	2.08	481	13.75
9	507	2.50	485	1.88	522	8.96	508	4.16	478	1.04	518	9.58
25	476	4.16	459	2.29	502	9.58	511	2.08	480	2.50	513	7.71

Note. RT = reaction time; PE = percentage error.

Stimuli. The stimuli were the letters L, upright T, and tilted T. The target stimuli were tilted T and L, and the upright T served as a context. Each of the stimuli appeared in three matrix sizes: 1-letter matrix, 9-letter matrix, and 25-letter matrix. The size of the context matrix was always identical to that of the target matrix. Stimulus presentation was similar to that of Experiment 5 (see Figure 4, displays with tilted Ts and Ls). The target stimuli appeared either centrally at the fixation point or 0.20° of visual angle to the left or to the right of the fixation point. When the target stimulus (either a tilted T or an L) was presented centrally, the context stimulus (an upright T) appeared randomly either to its right or left side. In the noncentral presentation, the target stimulus appeared 0.20° of visual angle to the left or to the right of the fixation point, and the context stimulus appeared 0.20° to the other side of the fixation point.

Design and procedure. Participants were required to discriminate between an L and a tilted T by pressing on either of two response keys at each presentation of the stimulus. On each trial a matrix of upright Ts, equal in size to the target matrix, was also present. The experiment used a repeated-measures three-factor design: Letter (tilted T, and L), Matrix Size (1 letter, 9 letters, or 25 letters), and Spatial Position (central, or noncentral). The different matrix sizes were administered in separate blocks for each spatial position. The order of the spatial position conditions as well as the order of the matrix sizes were counterbalanced across participants. The letters were randomized within blocks. Each block included 24 practice trials and 120 experimental trials. All other aspects of the procedure were identical to that of the previous experiments.

Results and Discussion

Mean RTs and PEs are presented in Table 7. A three-factor repeated-measures ANOVA (Letter × Matrix Size × Spatial Position) indicated a significant effect of matrix size, $F(2, 22) = 3.89, p < .05$, a significant effect of spatial position, $F(1, 11) = 16.12, p < .002$, and a significant interaction between number and spatial position, $F(2, 22) = 4.25, p < .05$, for RTs only. There was no significant effect of stimulus, for both RTs and PEs, $F\text{s} < 1$, and no significant interaction involving this factor. RTs increased with an increase in matrix size under the noncentral presentation but not under the central one. RTs were slower with noncentral than with central presentation, except for the one-letter matrix. These effects, however, were the same for tilted T and for L.

The present results show that a context of one upright T (or one matrix of upright Ts), that allowed participants to respond to disparities rather than to features of a single stimulus, did not act to generate the orientation advantage effect when the task called for a simple binary discrimination between a tilted T and an L. Recall that a context of one upright T (or one matrix of upright Ts) was found to be sufficient to produce the effect in discriminating an upright T from either a tilted T or an L (Experiment 5). How can this difference be explained?

Table 7
Mean RTs and PEs for Each Letter as a Function of Matrix Size Under the Two Spatial Certainty Conditions in Experiment 6

Matrix size	Central position				Noncentral position			
	L		Tilted T		L		Tilted T	
	RT	PE	RT	PE	RT	PE	RT	PE
1	579	2.36	572	2.91	572	4.58	572	4.03
9	571	3.75	564	3.47	635	5.42	642	4.03
25	586	2.36	587	4.44	675	3.47	664	4.72

Note. RT = reaction time; PE = percentage error.

When the task requires discriminating an upright T from either a tilted T or an L in the context of an upright T (Experiment 5), the two responses correlate perfectly with homogeneity.[3] One response corresponds to a perfectly homogenous display (all upright Ts), and the other response corresponds to some heterogeneity. The participants then could use, or be inadvertently affected by, their perception of homogeneity versus heterogeneity. In that case, detection of heterogeneity suffices to generate a response, and the more readily apprehended heterogeneity is, the faster and more accurate the response. That is, perception of homogeneity–heterogeneity when conjoined with relative judgment is sufficient to generate the orientation advantage effect.

On the other hand, when the task calls for discriminating a tilted T from an L in the context of an upright T, such a clue does not exist because no stimulus is homogenous. Apparently, participants cannot capitalize on the difference between heterogeneity that is readily perceived (due to orientation disparity) and heterogeneity that is hard to perceive (due to disparity in line arrangements). Therefore, no orientation advantage was observed in the present experiment.

Thus, relative judgment was found to be insufficient in itself to generate the effect in a simple binary discrimination task. Now, is there another condition that would be sufficient to generate the effect when conjoined with relative judgment?

The next experiment examined whether a larger context would be sufficient to produce the effect. It used the same discrimination task in a context of three upright Ts (or three matrices of upright Ts), and in a no-context condition as well.

Experiment 7

Method

Participants. Ten women and 6 men from 20 to 26 years old with normal vision participated in the experiment. None had participated in the previous experiments.

Stimuli. A tilted T or an L appeared in two conditions. In the context condition a quadruplet containing one-letter matrices or nine-letter matrices was presented. Each matrix occupied a quadrant of an imaginary square that subtended 0.49° × 0.49° and 1.63° × 1.63°, for one- and nine-letter matrices, respectively. Three of the matrices in the quadruplet were of upright Ts, and one of the matrices was of either tilted Ts or Ls. The matrix of the tilted Ts and the Ls appeared with equal frequency in each quadrant. In the no-context condition a single one-letter matrix or a nine-letter matrix of either tilted Ts or Ls was presented. Each matrix appeared in equal frequency in each quadrant of the imaginary square. A single one-letter matrix subtended 0.20° × 0.20°, and a single nine-letter

[3] Note that we use here the term *homogeneity* in a rudimentary sense that does not require multiplicity of elements. Two elements are enough.

matrix subtended 0.77° × 0.77°. Examples of the stimuli in the context and in the no-context conditions are presented in Figure 5.

Design and procedure. Participants were required to discriminate between an L and a tilted T by pressing on either of two response keys at each presentation of the stimulus. The experiment used a repeated-measures three-factor design: Context (context, no context), Letter (tilted T, L), and Matrix Size (one-letter, nine-letter). Each of the four combinations of context and matrix size were administered in four separate blocks, and their order was counterbalanced across participants. The letters were randomized within blocks. Each block included 32 practice trials and 128 experimental trials. The procedure was identical to that of the previous experiments.

Results and Discussion

Mean RTs and PEs are presented in Table 8. A three-factor repeated-measures ANOVA (Letter × Context × Size) performed on the RT data indicated a significant effect of context, $F(1, 15) = 19.17$, $p < .0005$, and a significant interaction between context and letter, $F(1, 15) = 18.55$, $p < .0006$. There was no significant difference in RT between a tilted T and an L when no context of upright Ts was present, $F < 1$. On the other hand, in the presence of upright Ts, a

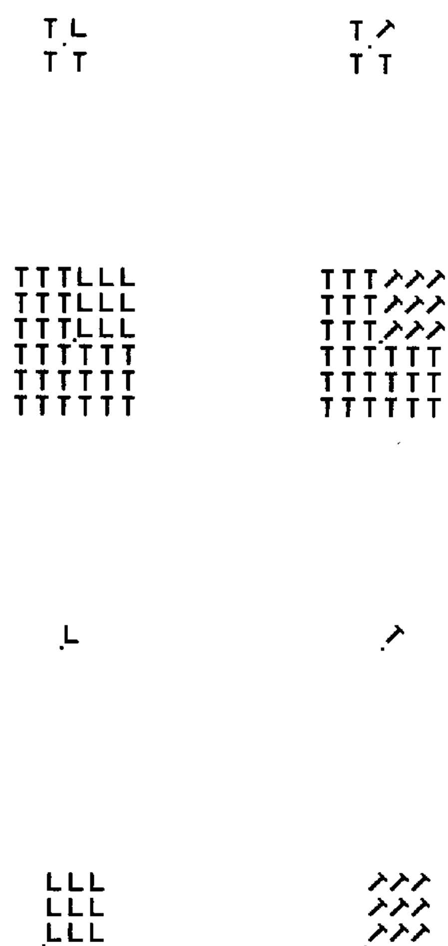

Figure 5. Examples of the stimuli used in Experiment 7 for the context condition (top) and for the no-context condition (bottom).

Table 8
Mean RTs and PEs for the Two Types of Stimuli as a Function of Matrix Size Under the Context and No-Context Conditions in Experiment 7

Matrix size	Context				No context			
	L		Tilted T		L		Tilted T	
	RT	PE	RT	PE	RT	PE	RT	PE
1	639	2.44	622	1.46	561	2.53	565	1.66
9	647	2.34	604	3.02	561	1.86	563	2.44

Note. RT = reaction time; PE = percentage error.

tilted T was responded to significantly faster than was an L, $F(1, 15) = 16.18$, $p < .0015$. The difference between a tilted T and an L in the context condition increased with an increase in matrix size (17 and 43 ms, for one- and nine-letter matrix, respectively), as indicated by the significant interaction among context, size, and letter, $F(1, 15) = 5.20$, $p < .05$. Analysis of the error rate data did not yield any significant effect.

The results show that when the task was to discriminate a tilted T from an L, a context of three upright Ts (or three matrices of upright Ts) gave rise to the orientation advantage effect. Recall that a context of only one upright T (or one matrix of upright Ts) was not sufficient to do so (Experiment 6).

Clearly, the distinction between homogeneity and heterogeneity, that seems to account for the sufficiency of a context of one upright T in discriminating an upright T from either a tilted T or an L (Experiment 5) is irrelevant for the present task, regardless of the number of the context stimuli, because all stimuli are heterogeneous. Why then was a context of three upright Ts found to be sufficient, but a context of one upright T (Experiment 6) was not?

One straightforward account is that the context of upright Ts seems to help in generating the effect only under one condition: When it serves in localizing the to-be-responded stimulus (or matrix). When there are two stimuli (or matrices), there is no way in which the presence of the context stimuli could contribute to localization. However, when there are four stimuli, the to-be-responded stimulus (or matrix) is the odd one out. Oddity could then be exploited for the sake of localization. The perception of the odd stimulus is clearly a process of relative judgment in which the advantage of orientation disparity can manifest its potential.

The problem with this account is, however, that in Experiment 2 orientation advantage did not vanish when cueing was supposed to minimize spatial uncertainty. Thus, localization is probably not necessary.

An alternative account assumes that the discrimination of an L from a tilted T does not require localization. Any stimulus array presumably generates a pattern of activation that serves to affect attention (Logan, 1996; Wolfe, 1994; Yantis & Jonides, 1990). Theoretically, there is no reason why *inputs* to the attentional system cannot in themselves be used for discrimination. Since oddity is a potent factor in attracting attention toward the disparate stimulus (Folk, Remington, & Johnston, 1992; Wolfe, 1994), it must also generate a potent salience. Thus, oddity does not necessarily act by aiding localization that serves to direct attention that in turn serves to facilitate identification or response processes, as the attention-summoning hypothesis suggests. The differential strength of the inputs to the attentional system given rise to by oddity of orientation on the one hand and oddity of line arrangement on the other hand may suffice as a basis for making a choice response. If such a clue has been capitalized on by participants, deliberately or inadvertently, that may help to explain both the significant effect of context in the present experiment and the null effect of attentional cueing observed in Experiment 2.

General Discussion

We try here to explore the source and the locus of the orientation advantage effect. This effect refers to the finding, originally demonstrated by Beck (e.g., 1972), that in a multiple-stimuli presentation, but not in a single-stimulus presentation, a discrimination between line orientations (as between an upright T and a tilted T) is easier than a discrimination between line arrangements (as between an upright T and an L).

We first ruled out the possibility that the absence of orientation advantage in a single-stimulus presentation is due to poor sensitivity of the test. For that matter, we used a task in which both L and tilted T were optional alternatives to an upright T in the same block, and measured both RT and accuracy, in both single-stimulus and multiple-stimulus presentations. Our tests confirmed the absence of orientation advantage in a single-stimulus presentation (Experiment 1).

We then proceeded to specify the conditions under which the orientation advantage effect is manifested. We demonstrated that the effect did not vanish, nor was it reduced, when the field could be segregated well by proximity (Experiments 2, 3, and 5). This finding argues against hypotheses that ascribe the effect to processes that are sensitive to adjacency between elements (e.g., the local statistics hypothesis), and it suggests that the process of segregation is not necessary for the manifestation of the orientation advantage effect.

The effect seems to be magnified when the number of stimuli increases, but it was observed both with single letters and with groups of letters (Experiments 2–5, and 7). Presenting a group of stimuli was found to be neither sufficient nor necessary for the emergence of the effect. Presentation of a group of identical letters rather than a single letter did not generate the effect in a single-stimulus presentation (Experiment 1), and on the other hand, the effect was observed when a single letter rather than a group of letters served as a context (Experiment 5). These findings suggest that the effect is not due to some property that emerges when a number of stimuli having the same attribute are presented together, as the group-property hypothesis argues, nor to processes hypothesized to be involved in the analysis of multielement stimuli, as the global computation hypothesis argues. Yet, the number of elements does seem to affect the size of the effect, suggesting that the processes involved in the effect are sensitive to this factor. We return to this point later.

The effect also seems to be insensitive to eccentricity (at least within the eccentricity ranges explored here), as it was the same both under central and under more peripheral presentation, although general speed of discrimination decreased with eccentricity (Experiment 4).

Furthermore, we demonstrated that the orientation advantage effect was still as strong under spatial certainty, either when the potentially disparate region was cued in advance (Experiment 2), or when its location was fixed (Experiment 5, central presentation). These findings suggest that the effect is not sensitive to location uncertainty, nor does it seem to reside in attentional processes such as shifting or summoning of attention, as the attention-summoning hypothesis implies. They also argue against the diffuse-attention hypothesis that attributes the effect to the difference in the amount of available resources under conditions of focal attention and diffuse attention (as suggested by Beck, 1972; see our discussion of Experiment 2).

Thus, our results suggest that the two premises shared by the accounts presented in the Introduction seem unnecessary: Neither is the orientation advantage effect mediated by processes of segregation, nor is it a function of processing a group of elements versus processing of single elements. It also seems to be insensitive to both attentional factors and location uncertainty.

On the other hand, our results make it clear that the effect *cannot* be obtained when the imperative stimulus (a tilted T or an L) is presented without any upright T in the neighborhood. In other words, relative judgment is a necessary condition for the manifestation of the orientation advantage effect.

Is relative judgment a sufficient condition as well? That is, is simultaneous presentation of an upright T sufficient for the manifestation of the effect? The answer seems to be negative: When the task called for discriminating a tilted T from an L in the context of an upright T, a context of one stimulus was not found to be sufficient for producing the effect (Experiment 6).

Since relative judgment was found to be insufficient to generate the effect in itself, the question was then whether there is a condition (or a set of conditions) that would be sufficient to generate the effect when conjoined with relative judgment. We found two such conditions. One condition is when simultaneous presentation renders the perception of homogeneity–heterogeneity sufficient to determine a response, as, for example, in discriminating an upright T from either a tilted T or an L in the context of an upright T. In this case a context of one upright T (with one tilted T or an L), or one matrix of upright Ts (with an equal-sized matrix of tilted Ts or Ls), suffices to give rise to the effect (Experiment 5). Another condition is when simultaneous presentation gives rise to oddity, as, for example, in discriminating a tilted T from an L in the context of a number of upright Ts. In this case a context of one stimulus was not found to be sufficient for producing the effect (Experiment 6), but a context of three stimuli was (Experiment 7). That is, the relevant stimulus needs to be the odd one out, or more generally, the ratio between the number of stimuli and the number of context stimuli must be less than unity.[4]

The finding that perception of homogeneity–heterogeneity or perception of oddity is involved in the orientation advantage effect can explain why number of elements, though not critical for generating the effect, seems to affect its size. For example, it seems quite plausible that homogeneity–heterogeneity is more readily apprehended when groups of identical stimuli, rather than single stimuli, are presented.

We have discussed (see Discussion of Experiment 7) two possible accounts for the role of oddity in generating the effect. One refers to the process of localization of the relevant stimulus. It suggests that orientation advantage may be manifested only when disparity can aid the localization of the to-be-responded stimulus. When there are two stimuli (or two homogeneous matrices), however discriminable the stimuli are, disparity cannot serve in localization. Only when the relevant stimulus is the odd one out can localization take advantage of disparity. Some support for this account seems to come from findings that an orientation-defined target (or target texture) is easily localized (e.g., Nothdurft, 1991, 1992), and that its identification is superior to that of its surrounding stimuli (Scialfa & Joffe, 1995). Scialfa and Joffe also showed that target presence interfered with the identification of the nontarget stimuli even when participants were required to identify only the surround orientation.

Our results, however, suggest that neither localization nor shifting of attention are necessary for the emergence of the orientation advantage effect. In addition, there are findings that show that participants can detect an orientation-defined target without knowing what or perhaps where it is (Attkinson & Braddick, 1989; Sagi & Julesz, 1984, 1985).

The alternative account seems to fare better because it suggests a process that does not require localization. According to this account participants may use, or be affected by, the strength of the input to the attentional system, namely the high salience given rise to by oddity of orientation versus the low salience given rise to by oddity of line arrangement. This notion may account both for the critical role of oddity for the emergence of the effect, and for the insensitivity of the effect to attentional factors and location uncertainty.

It follows from this account that salience may be necessary for localization (Sagi & Julesz, 1984) and for directing attention (e.g., Theeuwes, 1991) to the relevant stimulus, but it does not entail that localization or an attention shift occurs. Support for this view comes also from studies that suggest that a salient singleton does not necessarily capture attention (e.g., Folk & Annett, 1994; Yantis & Egeth, 1994). It has been further suggested that capturing of attention by a salient singleton may depend on the state of attentional readiness or control setting adopted by the participants in response to task demands (Bacon & Egeth, 1994; Folk et al., 1992; Folk, Remington, & Wright, 1994).

The difference between processes that require localization and processes that do not require localization may also help to explain some inconsistencies that concern the role of interelement separation in visual search and texture segmentation. Several studies indicated that for a given orientation disparity, the efficiency of detecting a target (Sagi & Julesz, 1987) or segmenting a texture (Nothdurft, 1985) depends critically on the spacing between the elements. On the other hand, our results showed that detection of orientation disparity was independent of the separation between the stimuli (Experiments 2–5). Similarly, Bacon and Egeth (1991) showed that target–nontarget separation had no effect on the search for an orientation-defined target. This apparent discrepancy can be resolved by considering possible processes that determine or affect response. As mentioned earlier, task demands may encourage different modes (Bacon & Egeth, 1994; Folk et al., 1992). Even for a certain task, more than one mode may be possible (e.g., Pashler, 1988), and participants may resort, deliberately or inadvertently, to an easier mode if they could (Bacon & Egeth, 1994). Spacing between the stimuli may be critical when a process of localization is involved, but not when participants perform the task in ways that do not require localization. Presumably, the participants in Nothdurft's and in Sagi and Julesz's experiments resorted to a mode that required localization. This was either because localization was necessary for performing the task (Nothdurft, 1985, Experiments 2–4, in which participants were required to detect the global figure of a region formed of lines differing in orientation from the background lines), or perhaps because salience was not sufficient for making a response due to factors that affected the conspicuity of the target (Sagi & Julesz, 1987; see Bacon & Egeth, 1991, for possible confoundings in Sagi & Julesz's experiment). Consequently, a reduction in performance with increased interelement separation was observed. On the other hand, the participants in our experiments and in that of Bacon and Egeth's (1991) could capitalize on, or be affected by, salience inputs or by the perception of homogeneity–heterogeneity, both of which do not require localization, and thus no effect of separation was observed.

In sum, it seems that though some of the accounts presented in the Introduction might have some grain of truth in them, most are not necessary for accounting for our results as well as for other relevant ones. Because location uncertainty, need for segregation, and, to a great extent, number of stimuli were not critical, parsimony favors the relative judgment hypothesis: In relative judgment, orientation disparity is perceived more readily than disparity in line arrangement. That advantage surfaces in certain conditions. We identified two such conditions: when the response set correlates (a) with apprehensions of homogeneity–heterogeneity or (b) with strength of inputs to the attentional system (salience). The advantage does not surface either when such processes are infeasible or useless, or when the task involves absolute judgment of orientation or line arrangement.

Our conclusion that the key to the orientation advantage effect is relative judgment is certainly compatible with the view that detection of orientation disparity, rather than detection of orientation per se, is a necessary condition for both spontaneous texture segmentation from orientation and fast visual search for an orientation-defined target (Noth-

[4] This is the reason that the effect cannot be attributed to singleton perception per se.

durft, 1992; see also the bottom-up component in the Guided Search model, Wolfe, 1994). Our results also suggest that the effect requires something else to be manifested (e.g., the perception of heterogeneity–homogeneity or of oddity).

The major theoretical significance of the reported results lies in the doubts they cast on several hypotheses about sources, loci or necessary conditions of the orientation advantage effect. Identifying relative judgment as the necessary condition clearly constrains possible process models but does not entail a single model. Any complete process model for the effect should take into account that simultaneity of stimuli is necessary, rather than processes that are hypothesized to be involved in segregation, in analysis of multielement stimuli, or in modulation in visual attention. Whether the effect is due to the effects of context on the perception of the imperative stimulus or to "emergent properties" that arise from interactions between the simultaneously presented stimuli is yet to be determined. Some hint for the former comes from the finding that the effect was manifested when the imperative stimulus was presented constantly at fixation more than when both stimuli were presented at the two sides of fixation (Experiment 5), but further research is needed in order to decide between these two classes of models.

Finally, in what way does orientation disparity (of the sort exemplified in our experiments) differ from line arrangement disparity (of the sort exemplified in our experiments)? We can only speculate. First, orientation is a separable feature, whereas line arrangement is a property derived from two other features. If features conjunctions qualitatively differ from single features (e.g., Treisman, 1982), derived properties must be even more so. This does not affect absolute judgment in which participants may relate to names (e.g., T vs. L). In relative judgment though, relating to feature disparity becomes possible and useful. Second, orientation is a continuum, hence providing an anchor may facilitate judgment. On the other hand, line arrangement is not a continuum but rather a nominal variable. In much the same way as a religion cannot serve as a good anchor for discriminating between two other ones (but age can), so is the case with line arrangement. Third, separable features that are spatially contiguous often interact, even across object boundaries. Derived properties like line arrangement do not interact that much, because they depend on local (intraobject) feature interactions. Those interactions need not be "emergent properties," but they might. Note, however, that the issue of the difference between orientation and line arrangement is subsidiary to the issue of when orientation advantage is or is not manifested.

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