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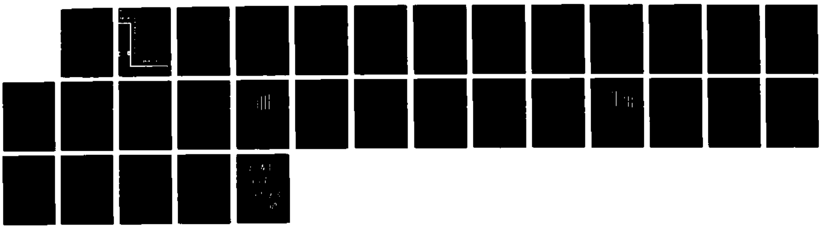

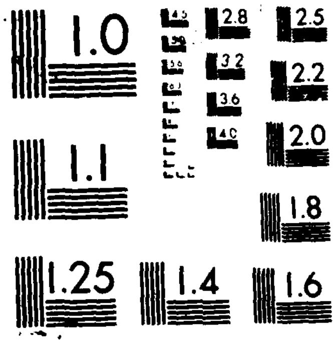
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VISUAL ATTENTION EFFECTS ON DISCRIMINATION OF LINE ORIENTATION AND LINE ARRANGEMENT

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Visual Attention Effects on Discrimination of Line Orientation and Line Arrangement

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The distinction between visual processes that require focused attention and those that use more diffuse or global attention is largely based on studies of visual search and texture segregation. It has been inferred from these studies that stimuli differing in the orientation of their component line segments can be distinguished without focal attention, whereas stimuli that differ only in the arrangement of line segments cannot. However, in most of this research, the locus of attention has not been explicitly manipulated in order to see what effect attention has on line orientation and line arrangement discrimination. In the first of the present experiments, while maintaining central fixation, attention was directed to a relevant peripheral target by a cue presented in the appropriate location. Discrimination of targets that differed in orientation of lines (slanted 45° either right or left of vertical) was minimally facilitated as the time between the onset of the valid cue and the onset of the target (cue-target stimulus onset asynchrony, SOA) was increased from 17 msec to 268 msec. On the other hand, discrimination of targets composed of two conjoining line segments (sideways Ts) required time to shift and focus attention, and benefits increased with longer cue-target SOAs that allowed attention to accumulate at the target.

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To test whether orientation discrimination would be affected by focusing attention elsewhere in the visual field, a second experiment was conducted in which a cue misdirected attention on 20% of the trials. A decrement occurred on incorrectly cued trials in comparison to correctly cued trials for both types of stimuli, SLANTs and Ts. Differences in the effect of attention on discrimination of the two types of stimuli may occur because only discrimination of Ts requires engagement of focus of attention on the target. On the other hand, both SLANTs and Ts may be affected by disengagement of attention from an incorrectly cued location.

SUMMARY

In looking at characters on a page, some characters seem to "pop out." One example is a slanted line among a group of vertical lines. It has been assumed that this phenomenon occurs because the response to such stimuli is automatic or preattentive. If this is true, does focal attention have an effect on discrimination of such stimuli? In the first experiment, attention was directed to characters in peripheral vision while the eyes remained stationary. It was found that discrimination of the direction of a slanted line was minimally facilitated by time to shift attention to the target, whereas discrimination of the direction of a target composed of two line segments (a sideways T) required time to shift and focus attention and benefited from longer periods that allowed attention to accumulate at the target. In a second experiment, it was shown that accuracy was much poorer if attention was misdirected to a nontarget area, for both discrimination of slanted lines and discrimination of Ts. Differences in the effect of attention on discrimination of the two types of stimuli may occur because only discrimination of Ts requires focus of attention on the target. On the other hand, both SLANTs and Ts may be affected by removal of attention from an incorrectly cued location.

PREFACE

This report represents a portion of the research program accomplished under Project 2313; Task 2313T3, Perceptual and Cognitive Dimensions of Pilot Training, Dr. Elizabeth L. Martin, Task Scientist. The division has an on-going basic (6.1) research program in visual attention to provide knowledge needed in order to understand attention to the visual scene. This knowledge is of benefit to the AFHRL/OT 6.2 and 6.3 R&D programs which are dedicated to the development and evaluation of visual systems for use on flight simulators. The experiments reported here were conducted by Dr. Cheal while on a University Resident Research Program fellowship at the Operations Training Division, Air Force Human Resources Laboratory, Williams Air Force Base, Arizona.

The authors gratefully acknowledge the editorial comments of Drs. R. Evans, M. Houck, C. McCollough Howard, J. Kleiss, J. Lindholm, and E.L. Martin on an earlier version of this report.

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I. INTRODUCTION

Recent models of visual information processing have postulated multiple processes in which attention is a key component (Neisser, 1967; Reeves & Sperling, 1986; Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977; Treisman & Gelade, 1980). Much of this research involves putative shifts of visual attention in the absence of eye movements. Although some of this research is controversial, there is no doubt that shifting attention to a stimulus location results in more accurate and more rapid detection of a simple target, such as a spot of light (Bashinski & Bacharach, 1980; Posner, 1980; Shulman, Remington, & McLean, 1979), and more accurate and more rapid discrimination of more complex stimuli, such as letters (Eriksen & Hoffman, 1972a; 1972b; 1973; Holmgren, 1974; Jonides, 1980; Sperling & Melchner, 1978).

In spite of the usually strong effect of attention on visual discrimination, in some experiments attention has not improved performance. For instance, location cueing did not improve detection of a tilted T among upright Ts (Ambler & Finklea, 1976) or determination of whether five letters were a word or a nonword (Hardyck, Chiarello, Dronkers, & Simpson, 1985). A related example is the decrement in performance that is often associated with responses in which a cue shifts attention to an incorrect location (Posner, 1980). This effect was found to vary with different types of stimuli. For instance, there was a much smaller decrement associated with invalid cues if the target digit or letter was displayed in a field of dots than if the target was displayed in a field of a constant set of letters (Eriksen & Yeh, 1985). Single-feature targets suffered much less from invalid cues than did conjunctive targets (i.e., color and letter; Prinzmetal, Presti, & Posner, 1986).

These anomalous findings may mean that more than one process is involved in visual attention. Two processes are included in some recent models of visual information processing. They are identified variously with such terms as preattentive processes vs focused attention (Neisser, 1967), distributed attention vs concentrated attention (Beck & Ambler, 1972), global attention vs focused attention (Alwitt, 1981), global vs local processing (Martin, 1979), global vs detailed detection (Broadbent, 1977), and automatic processing vs controlled processing (Schneider & Shiffrin, 1977). In general, the first term of each group refers to a rapid process that allows parallel search and is unlimited in capacity. The second term refers to a slower process where search is serial and limited in capacity. These terms have been considered variously to be separate stages of processing, to be dichotomous types of processing, or to be ends of a continuum (Keren, 1976). That is, these distinctions may only be different names for the same two dichotomous or continuous processes (Keren, 1976), or for two separate stages (Hoffman, Nelson, & Houck, 1983). It is also possible that different pairs of terms refer to different processes.

Texture gradient experiments provide examples of stimuli that seem to fit the first term of each set above. Stimuli differing by one feature are clearly discriminated with a border evident between two sets of stimuli. This phenomenon has been demonstrated by differences in line orientation (Beck & Ambler, 1972; Callaghan, Lasaga, & Garner, 1986; Olson & Attneave, 1970), number of terminators (Julesz, 1981), line curvature (Olson & Attneave, 1970; Treisman, 1986), and color (Callaghan et al., 1986; Treisman, 1986). Attempts to determine the characteristics that result in the perception of boundaries between areas of different textures have indicated that discrimination is based on a few local conspicuous features (Julesz, 1981). These discriminations have been considered to require only global attention or preattentive processes, because they are made rapidly and are not affected by the number of elements in the field.

Some effort has been made to test the hypothesis that such stimuli do not require focal attention. A single letter (an L or a tilted T) was presented in a display of upright Ts (Beck & Ambler, 1972). A tilted T was discriminated better than was an upright L under these conditions, and attention did not facilitate detection of a tilted T in a field of upright Ts (Ambler & Finklea, 1976). However, if the field was limited to eight characters and the target location was correctly cued prior to stimulus presentation, there was no significant difference in accuracy of detection of an L or a tilted T (Beck & Ambler, 1973). It was only when two or more locations were cued, so that attention was distributed over the target and noise items, that there was a decrement in performance of detecting the L but not the tilted T.

In other experiments, features that allowed rapid texture decisions (such as one L among Xs) were the same features that were detectable by a rapid parallel process when tested with briefly presented stimuli (Bergen & Julesz, 1983). For these stimuli, there was no decrement in accuracy with more noise characters, and there was no improvement in accuracy if the interval between stimulus presentation and presentation of a mask was increased beyond 160 msec. In contrast, an L among Ts required 300 msec to reach asymptote.

The discrimination of a tilted T from an upright T, or an L from an X, is most likely made on the basis of line orientation, whereas the discrimination of an L vs an upright T is most likely made on the basis of the arrangement of line segments. The discrimination of line orientation could be thought of as an automatic response that is made without the need for focal attention. If it is automatic, then line orientation discrimination would be involuntary, would operate in parallel over the visual field, and would be independent of other tasks. In contrast, discrimination of line arrangement could be thought of as a controlled response in which focused attention is necessary (Kahneman & Treisman, 1984).

However, some data cast doubt on the hypothesis that "automatic targets" do not require focused attention. For example, Hoffman et al. (1983) interpreted their data to indicate that detection of "automatic targets" was dependent on allocation of spatial attention. In their experiments, observers were given dual tasks: a search task for a digit among letters, and detection of a flicker in one of four lights. A consistent mapping (CM) paradigm was used for the search task. Accuracy in reporting the location of the flicker decreased with increasing attention devoted to the search task. In addition, accuracy was higher if the search target was in the same area of the visual field as the flicker.

The present research was designed as a direct test of the need for spatially focused attention in discrimination of two different kinds of stimuli: stimuli that are typically assumed to be discriminated by automatic, global processes (lines of different orientation), and stimuli that are assumed to require focused attention (characters composed of lines that do not differ in orientation, such as sideways Ts). The method used was a variation of one used by Lyon (1986) to plot the time course of spatial attention effects on discrimination of the conjunction of line segments. This method contains elements of techniques used by Posner (1980) and Bashinski and Bacharach (1980). The key difference between the present research and the texture segregation and visual search experiments discussed earlier is that attention is manipulated directly by presenting a spatial cue in the area of the target a few milliseconds before the target is presented. In addition, this is the first report of the time course of effects of attention on orientation discrimination.

If the usual inference from the earlier studies is correct, and stimuli that differ in the orientation of their component lines are discriminated in the absence of focal attention, then do they benefit from focal attention? This possibility was tested in our first experiment. It was shown that discrimination of line orientation neither needed focal attention nor benefited from it nearly as much as did discrimination of line arrangement. This was true even when discrimination of the two stimuli was equated for overall difficulty.

If, as the results of this first experiment suggest, the process of orientation discrimination is relatively unaffected by focal attention to the target area, then it may also be unaffected by the focusing of attention elsewhere in the visual field (Kahneman & Treisman, 1984). On the other hand, decrements in reaction time are found even in detection of simple stimuli when the target location is incorrectly cued (Posner, 1980). Such data predict decrements in performance in orientation discrimination if attention is first directed to a nontarget location. These alternative predictions were tested in the second experiment by reducing the probability that the spatial cue would direct attention to the correct target area. That is, on some trials, the cue directed attention away from the target area. This misdirection of attention resulted in a decrement in accuracy for both orientation discrimination and discrimination of line arrangement.

II. EXPERIMENT 1

Method

Observers

Three right-handed women, 24 to 37 years of age, with normal or corrected-to-normal vision and no previous experience in vision or attention experiments, were paid to participate in 24 approximately 1-hour sessions. In addition to the hourly salary, the observers could earn a bonus based on overall accuracy for each stimulus set. The bonus was used to increase motivation for accuracy.

Apparatus

Stimuli were displayed on an IBM enhanced color monitor with a luminance of 4 foot-lamberts (phosphors: P-22-B, P-22-G, and P-22-R, all with decay to 10% in less than 1 msec). An extended character set was generated in order to present the desired characters. An adjustable chin rest helped to maintain head position at a distance of 29 cm.

Short duration of stimulus presentation prevented any facilitation of responses by eye movement. In fact, an eye movement would have reduced response accuracy under some conditions because of saccadic suppression. However, in order to provide confirmation that fixation was maintained by the observer prior to responding, eye movement was monitored continuously with a video camera. Eye monitoring also allowed the experimenter to give the observers feedback that helped acquisition of the task.

Stimuli

Two types of stimuli were presented in separate blocks of trials. The stimuli were chosen to provide tests of (a) discrimination of line orientation, and (b) discrimination of line arrangement. Stimulus sizes were chosen empirically to approximately equate the discriminability of the two types of

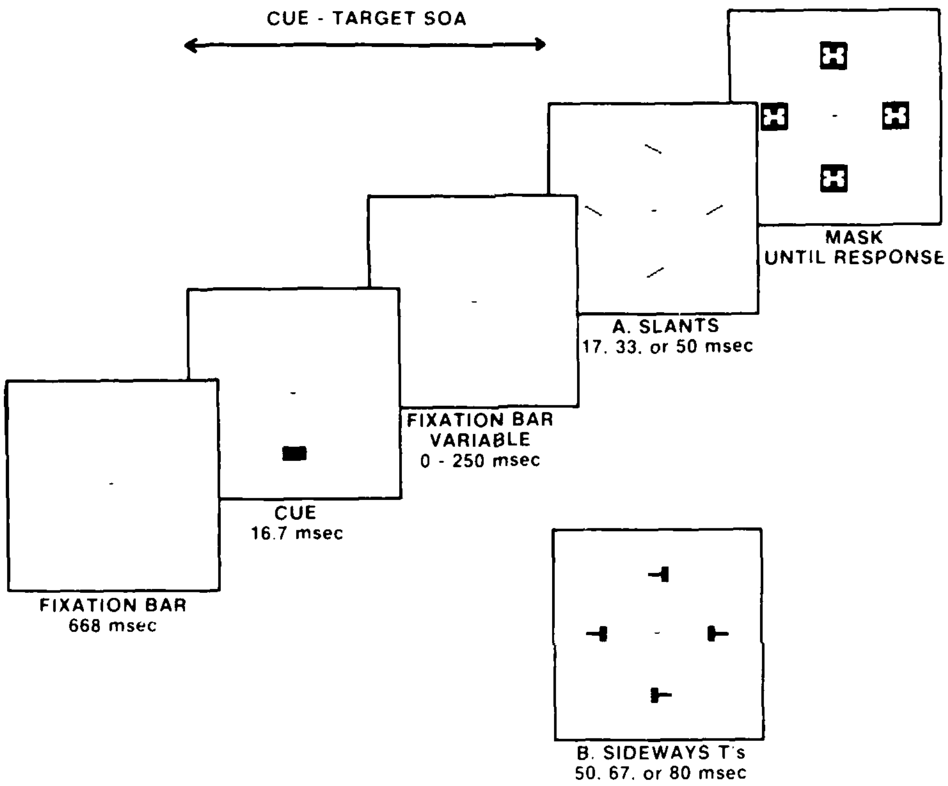


Figure 1. Sequence of Stimulus Events in Experiment 1. The two types of stimuli (A: SLANTs; B: SIDEWAYS Ts) were presented in separate blocks of trials. The actual stimuli were composed of white pixels on a dark gray screen.

stimuli. The first stimulus type (SLANT) was composed of a 1^{o} straight line, composed of five pixels, slanted at a 45-degree angle with the top of the line pointing either clockwise (right) or counterclockwise (left) (Figure 1, A). The second stimulus type (T) was formed by a 0.8^{o} horizontal line, composed of two rows of four pixels each, that extended either right (⊢) or left (⊣) from the center of a 0.8^{o} vertical line, composed of eight rows of two pixels each (total number of pixels = 24; Figure 1, B). The white pixels were presented against a dark gray background.

Procedure

Observers were seated comfortably in front of the computer monitor with room lights on. They were instructed to maintain fixation on a bar of light (0.2^{o} X 0.4^{o}) in the center of the screen throughout each trial (Figure 1). The computer displayed frames of information at the rate of 60 per second. Thus, the duration of each frame was 16.7 msec. After 668 msec, a rectangular cue (0.7^{o} X 1.2^{o}) appeared in one of four locations: 9^{o} above or below, or 8^{o} right or left of fixation. The duration of this cue was one frame (16.7 msec). The cue was followed by an interval of variable duration (0 - 250 msec) with only the fixation point. Thus, the latency from onset of the cue to onset of the target, the stimulus onset asynchrony (cue-target SOA), varied (16.7, 34, 50, 67, 84, 100, 117, 134, 150, 167, 200, 234, or 267 msec). At the end of the SOA, stimuli appeared at each of the four locations: 7.5^{o} above or below, and 6.4^{o} right or left of fixation. The target was the stimulus that appeared in the location that had been cued.

Trials were blocked by type of stimulus. For SLANT stimuli, durations were 1, 2, or 3 frames (17, 33, and 50 msec); for T stimuli, durations were 3, 4, or 5 frames (50, 67, and 84 msec). Appropriate durations were determined in pilot tests to provide approximately equal overall probability correct. It was hoped to obtain approximately 75% overall correct trials across observers (chance = 50%). Three durations were used to allow for individual observer differences.

Independent randomization within each block of 100 trials was used for each stimulus set. Within each block, four cue-target locations (right, left, above or below fixation), 13 cue-target SOAs, three stimulus durations, and two stimulus orientations (left or right) were independently randomized.

The stimuli were followed by a 1.4^{o} X 1.6^{o} mask (see Figure 1) that remained lit until the observer responded. The mask was an approximate negative image of the combination of the possible stimuli.

To respond, the observer pressed the right or left arrow key (numerals 4 or 6) on the computer keypad to indicate that the orientation of the stimulus in the cued position was right or left. After the response was entered, feedback of "CORRECT" or "WRONG" appeared at the fixation position, and the next trial was initiated.

In the initial session, each observer received 50 training trials with one type of stimulus presented for 320 msec, to familiarize her with the procedure and the stimuli. These practice trials were followed by five blocks of 100 trials each, using the same stimulus set at the durations indicated above. The observer then received 50 training trials with the other stimulus set presented for 320 msec to become acquainted with these stimuli, followed by five blocks of 100 trials each with this stimulus set presented for the appropriate durations.

During subsequent sessions, each observer completed five blocks of 100 trials on each stimulus set. Thus, each observer had a total of 1,000 test trials during each of 24 sessions. The starting stimulus set was counterbalanced across observers and alternated daily for each observer.

Data were collected on an IBM-XT computer. Preliminary daily analyses provided overall proportion correct for each stimulus set, proportion correct for each stimulus duration for each stimulus set, and proportion correct for each stimulus duration for each cue-target interval for each stimulus set for each observer. These same three calculations were computed for both individual and total sessions. Additionally, mean proportion correct for all durations was computed for each observer at each cue-target interval for each stimulus set. These data were graphed for each observer.

Statistical Analyses

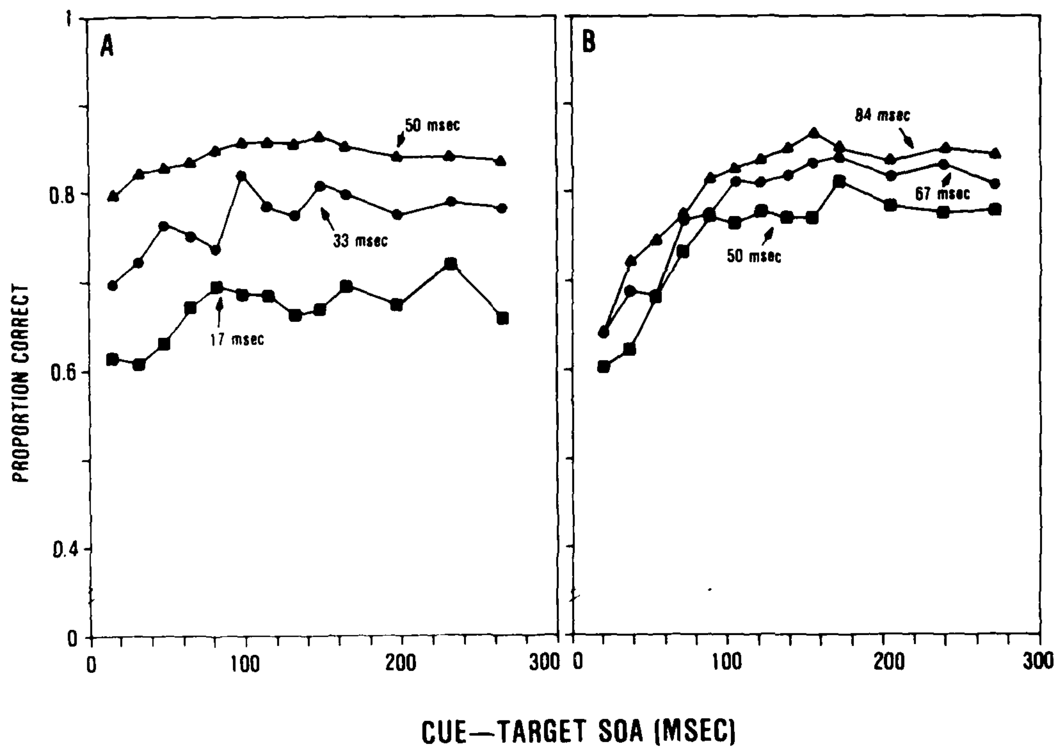
The 72,000 trials were analyzed with the SPSS-X release 2.2 Hierarchical Log-linear analysis program on Digital Equipment Corporation VAX-11/780 VMS system. All variables were included as grouping factors for the first analysis: stimulus type (SLANT and T), stimulus duration (short, medium, and long), cue-target SOAs, target orientation, location, and observer. The data were conceptualized as coming from a multidimensional contingency table, with the various factor levels along with the response variable (correct-incorrect) defining the cells of the table. A Chi-Square test of independence is often performed for a simple two-way table. This log-linear test is similar to the test of a row-by-column interaction. If the rows of the two-way table represent the levels of an independent variable and the columns represent the response or dependent variable, a significant Chi-Square statistic is evidence that the independent variable has an effect on the dependent variable. If the observed Chi-Square is very small then it might be concluded that the independent variable has no effect on (is independent of) the dependent variable. The log-linear model approach (Fienberg, 1980) extends this concept to contingency tables of higher dimensions. Of particular interest is whether or not the various independent variables interact with the response variable (correct vs incorrect response). Further interpretations of the various significant interactions were based on additional partial analyses.

Results

Overall analyses. The log-linear model test revealed significant effects of all variables and many significant interactions. Proportion of correct responses was well above chance (total probability correct = .76; $X^2[1]$ = 21,6311.94,

$p < .0001$). The effect of accuracy as a function of cue-target SOA ($X^2[12] = 720.27$, $p < .0001$) supports previous research in this paradigm in which an increase in accuracy with longer cue-target SOAs was shown (Lyon, 1986).

<u>SLANT</u> - <u>T comparisons</u>. The hypothesis that SLANTs do not require focused attention whereas Ts require focus of attention was supported by the significant interaction of accuracy as a function of stimulus and cue-target SOA ($X^2[12] = 156.10$, $p < .0001$). In addition, this interaction did not differ as a result of experience in the task. An analysis was computed using sessions as a variable (grouping sessions 1-6, 7-12, 12-18, and 19-24). There were no significant interactions of accuracy with session X cue-target SOA ($X^2[36] = 47.65$, $p = .0927$) or with sessions X cue-target SOA X stimulus type ($X^2[36]$



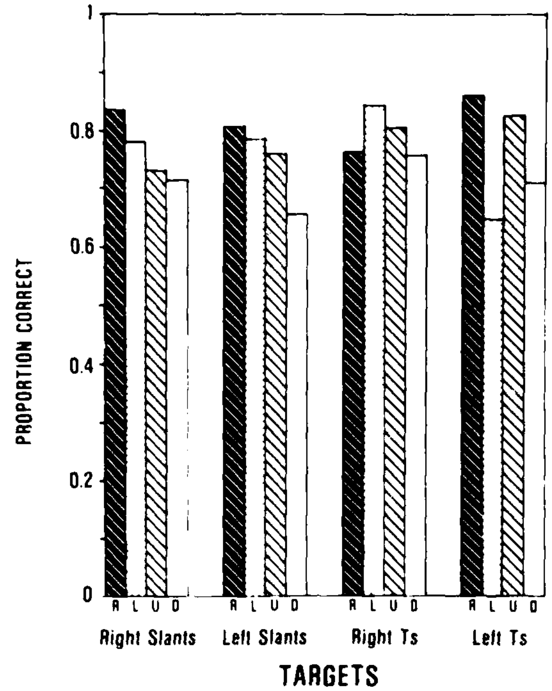
<u>Figure 2</u>. Proportion Correct as a Function of Cue-Target SOA in Experiment 1. Three separate durations of stimulus presentation were used. Standard deviation of the proportion was less than the size of the symbols. A. SLANTs: 17 msec, squares; 33 msec, circles; 50 msec, triangles. B. SIDEWAYS Ts: 50 msec, squares; 67 msec, circles; 84 msec, triangles.

= 36.20, p = .4592). Thus, the statistics support the effect seen in Figure 2. That is, the increase in accuracy with longer cue-target SOAs was much larger for T stimuli ($X^2[12] = 766.12$, $p < .0001$) than for SLANT stimuli ($X^2[12] = 122.74$, $p < .0001$).

Even though there were significant effects of the observers ($X^2[2] = 801.19$, $p < .0001$), there was no significant interaction of the observers with stimulus type ($X^2[5] = 3.20$, $p = 0.202$). In fact, these statistics were consistent across observers. For each observer, there was a significant interaction of accuracy as a function of cue-target SOA and stimulus type (NR: $X^2[12] = 74.14$, $p < .0001$; SB: $X^2[12] = 59.76$, $p < .0001$; SS: $X^2[12] = 63.66$, $p < .0001$), and the interaction of accuracy X stimulus type X cue-target SOA X stimulus duration was not significant for any of the three observers (ps = .609, .718, and .054, respectively). Thus, the differences in the observers did not alter the conclusions as to the difference between SLANTs and Ts.

It was anticipated that there would be significant effects of stimulus duration; i.e., more accuracy with longer-duration stimuli ($X^2[2] = 958.39$, $p < .0001$). It was also anticipated that observers would differ. For this reason, three different durations were used for each stimulus type in an effort to compensate for differences in accuracy of the observers. The three stimulus durations were also used in an effort to equate the overall accuracy of the two types of stimuli. This was not completely successful as there was an effect of stimulus type on accuracy (SLANT: probability correct = .745; T: probability correct = .775; $X^2[1] = 30.91$, $p < .0001$), and a stimulus X stimulus duration X accuracy interaction ($X^2[2] = 194.14$, $p < .0001$), as well as an observer X stimulus type X stimulus duration X accuracy interaction ($X^2[4] = 12.78$, $p < .02$). However, even though there were differences in accuracy as a function of stimulus duration between SLANTs and Ts, the effect of stimulus type on cue-target SOA was similar for each stimulus duration ($X^2[24] = 20.32$, $p = .6783$). In the case of Ts, accuracy as a function of stimulus duration and cue-target SOA was not significant ($p = .4010$). For SLANT, where there was a larger effect of stimulus duration, X^2 was significant only at the .05 level.

Target location effects. Accuracy varied as a function of the location of the target ($X^2[3] = 606.62$, $p < .0001$). Generally, responses were most accurate when targets were on the right (probability correct = .812) and least accurate when targets were below fixation (probability correct = .714). There was somewhat greater accuracy when the target was oriented toward the right (overall probability correct = .776) than when it was toward the left (overall probability correct = .743; $X^2[1] = 54.44$, $p <$ .0001). This difference was dependent on location ($X^2[3] = 303.91$, $p \leq .0001$) and on location as a function of stimulus type ($X^2[3] = 366.84$, $p < .0001$). For both right- and left-oriented SLANTs, responses were most accurate if



<u>Figure 3</u>. Proportion Correct as a Function of Location of Target in Experiment 1. Location was right (R), left (L), up (U), or down (D) for SLANTs that faced right or left, and for Ts that faced right or left. Standard deviation of the proportion < .01 for each bar.

the target was right of fixation. On the other hand, right-oriented Ts were discriminated best on the left and left-oriented Ts were discriminated best on the right (Figure 3). It is possible that this effect is due to better acuity for stimuli that are closer to the fovea. For right-oriented Ts on the left and for left-oriented Ts on the right, the horizontal extender faced nasally. In these cases, the end of the line was approximately 1.2° closer to fixation than when the T faced temporally.

It should be noted that responses to SLANTs tended to be more consistent across locations and target orientations than did responses to Ts. The order of accuracy across locations was consistent for the three observers with SLANTs, but was not consistent with Ts. Also the bias toward more accuracy when targets were oriented to the right was consistent across locations, whereas it was not consistent with Ts. Most of the data here are consistent with earlier data that show that observers perform best when stimuli are to the right of fixation (Chastain, 1983; Hardyck et al., 1985).

III. EXPERIMENT 2

In Experiment 1, it was shown that discrimination of line orientation is minimally facilitated by an opportunity to focus attention on the location of the stimulus. This is in contrast to discrimination of the arrangement of like-oriented, conjoined line segments where there is a clear advantage on trials in which time is given to permit shift and focus of attention. Thus, discrimination of line orientation neither requires focused attention nor benefits from time to focus attention. In these ways, discrimination of line orientation appears to be an automatic process.

It has been said that automatic processes are not subject to interference from attended activities (Kahneman & Treisman, 1984). Thus, if these stimuli are strongly automatic, they should not be impaired by shifting attention away from the location of the stimulus. This supposition was tested in Experiment 2 by including some trials in which the cue to shift attention was invalid; i.e., the spatial cue was located in an area other than the one in which the target was presented.

Procedure

Experiment 2A

The same three observers used in Experiment 1 were tested for an additional 10 sessions (1,000 trials per session) on a variation of the paradigm used in Experiment 1. The procedure differed from the procedures in Experiment 1 only in the details described below. Following the cue, only one target appeared in one of the four possible locations. The target appeared in the same location as the cue on 80% of the trials and could appear in any of the other three locations (randomized) on 20% of the trials. "O"s appeared at the other three locations (Figure 4).

Only four cue-target SOAs were used: 33, 67, 100, and 134 msec. Stimulus durations were chosen in order to approximately equate total proportion correct for the two conditions: SLANTs, 33 and 50 msec; Ts, 50 and 67 msec. Thus, within each block of 100 trials, four cue positions, four cue-target intervals, two stimulus durations, four target locations, and two target orientations were independently randomized, with the provision that the target location would be in the cue location on 80% of the trials. The two types of targets (SLANTs and Ts) were presented in separate blocks as in Experiment 1. Order of target type was counterbalanced across observers, and alternated each day for each observer.

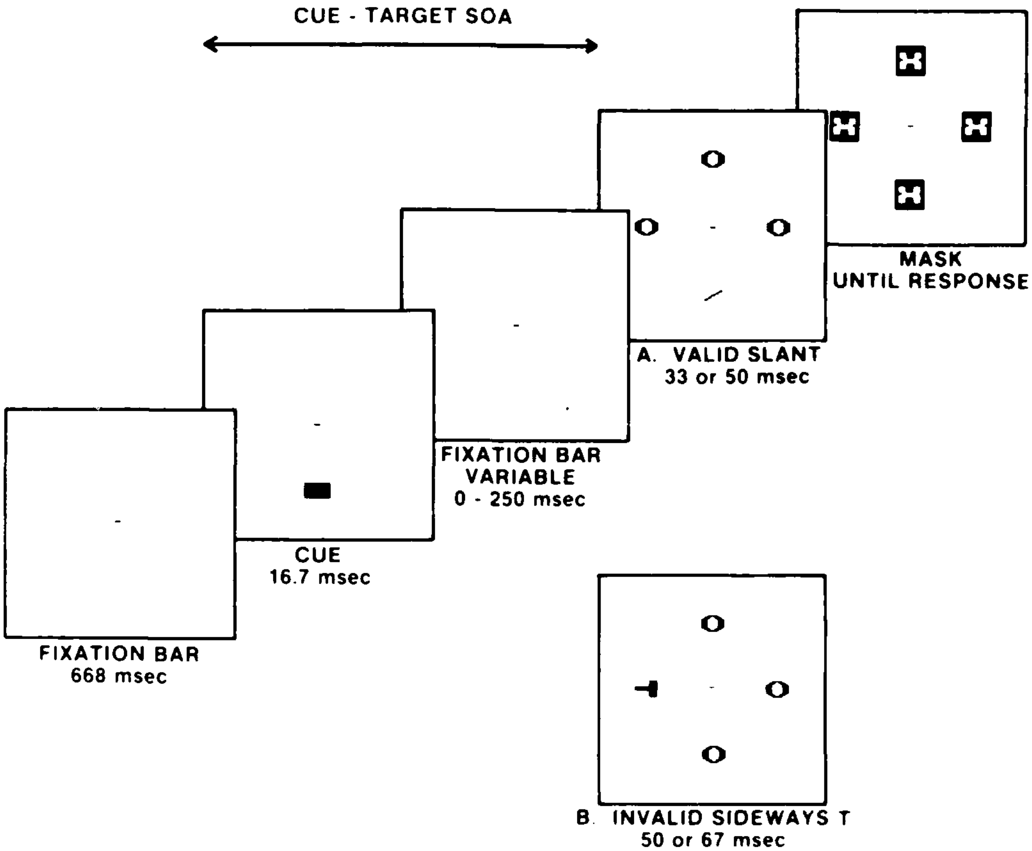


Figure 4. Sequence of Stimulus Events in Experiment 2. The two types of stimuli (A: SLANT; B: SIDEWAYS T) were presented in separate blocks of trials. A: A validly cued trial; B: An invalidly cued trial. The actual stimuli were composed of white pixels on a dark gray screen.

Experiment 2B.

Observers in Experiment 1 completed a large number of trials with a valid cue. Therefore, responses to shift attention to the location of the cue may have become automatic (Kahneman & Treisman, 1984), and a decrement found on invalid trials in Experiment 2A may have been due to this lengthy training. This possibility necessitated the testing of two naive observers using the same procedures as in Experiment 2A.

On Day 1, two observers (female), naive to visual research (one right-handed and one left-handed, 27 and 28 years of age) were given 50 trials with one target type (SLANT or T) presented for a duration of 320 msec. They then received five blocks of 100 trials with the same target type, with the two appropriate stimulus durations randomly assigned by the computer program. When these trials were completed, the observers were given 50 trials with the other target type, presented for 320 msec. The session was completed with five blocks of 100 trials on the second target type, with the two appropriate stimulus durations. On the next nine sessions, each observer completed five blocks of 100 trials for each target type.

Results

Overall analyses. The log-linear model test was computed for Experiment 2A and Experiment 2B separately. In both experiments, as in Experiment 1, there were significant main effects of all variables and many interactions. There were significantly more correct responses than incorrect (Experiment 2A: $X^2[1] = 20,346$; Experiment 2B: $X^2[1] = 2057.90$, $p < .0001$). Experienced observers were significantly more accurate than naive observers (89% overall correct for experienced and 66% for naive). This difference was significant when Experiments 2A and 2B were analyzed together ($X^2[1] = 3744.74$, $p < .0001$). However, when observers were analyzed independently, there were no consistent statistical differences to separate responses of experienced observers from responses of naive observers that were not related to higher overall accuracy by the experienced observers.

SLANT - T comparison. A decrement was associated with invalid trials whether the target consisted of a conjunction of line segments (a stimulus that is thought to require focused attention) or a line orientation (a stimulus that is thought to neither require nor benefit from focused attention). There was significantly less accuracy on invalid trials than on valid trials for both SLANTs and Ts for observers who were experienced with always valid trials ($X^2[1] = 502.68$, $p < .0001$; Figure 5) and with inexperienced observers who were trained originally with the 80%-20% valid condition ($X^2[1] = 244.85$, $p < .0001$; Figure 6). In addition, there were larger valid-invalid differences with longer cue-target SOAs (interactions of accuracy with validity and cue-target SOA) for Experiment 2A ($X^2[3] = 121.79$, $p < .0001$) and Experiment 2B ($X^2[3] = 34.45$, $p < .0001$).

The principal effects of Experiment 1 were replicated in both highly experienced observers and in inexperienced observers, even though fewer cue-target SOAs were used. There was more accuracy with longer cue-target SOAs (Experiment 2a: $X^2[3] = 139.99$; Experiment 2B: $X^2[3] = 63.47$, $p < .0001$), and significant interactions of accuracy as a function of stimulus type and cue-target SOA (Experiment 2A: $X^2[3] = 31.68$, $p < .0001$; Experiment 2B: $X^2[3] = 10.09$, $p < .02$). This interaction was due to greater accuracy as cue-target SOAs increased for Ts, but not for SLANTs. For experienced observers, accuracy as a

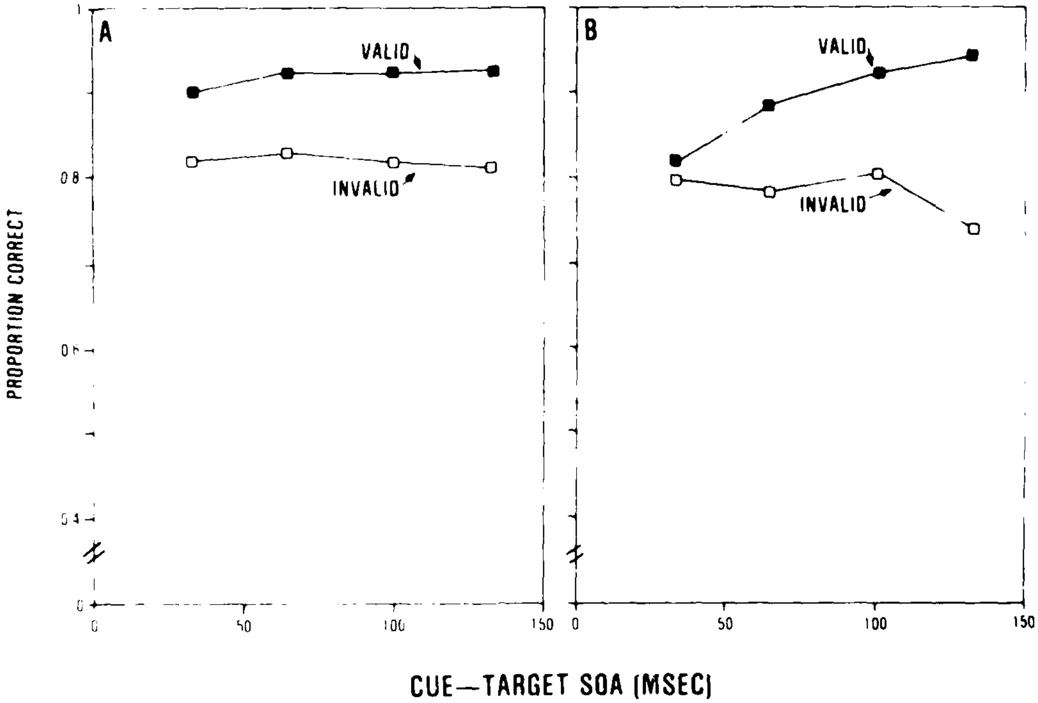


Figure 5. Proportion Correct as a Function of Cue-Target SOA in Experiment 2A. Mean of two durations of valid and invalid trials for experienced observers. A: SLANTs; B: SIDEWAYS Ts.

function of cue-target SOA was not significant for SLANTs ($X^2[3] = 7.51$, $p = .0573$), and this effect only reached marginal significance for naive observers ($X^2[3] = 9.14$, $p < .05$). For Ts, on the other hand, accuracy as a function of cue-target SOA was highly significant for both experienced observers $X^2[3] = 177.75$, $p < .0001$) and naive observers $X^2[3] = 66.19$, $p < .0001$).

There were also significant main effects: greater accuracy with SLANTs than with Ts (Experiment 2A: $X^2[1] = 87.39$; Experiment 2B: $X^2[1] = 53.93$, $p < .0001$), more accuracy with longer durations (Experiment 2A: $X^2[1] = 506.21$; Experiment 2B: $X^2[1] = 126.73$, $p < .0001$), and an effect of observers (Experiment 2A: $X^2[2] = 1022.40$; Experiment 2B: $X^2[1] = 107.75$, $p < .0001$). Once again the effect of duration did not interact with the stimulus type X cue-target SOA effect (Experiment 2A: $X^2[3] = 4.73$, $p = .193$; Experiment 2B: $X^2[3] = .394$, $p = .942$). As in Experiment 1, differences in total proportion correct due to longer target presentations did not change the effect of cue-target SOA.

Target location effects. The effect of location on accuracy was replicated in Experiment 2A ($X^2[3] = 844.65$, $p < .0001$) and Experiment 2B ($X^2[3] = 47.10$, $p < .0001$; Figure 7).

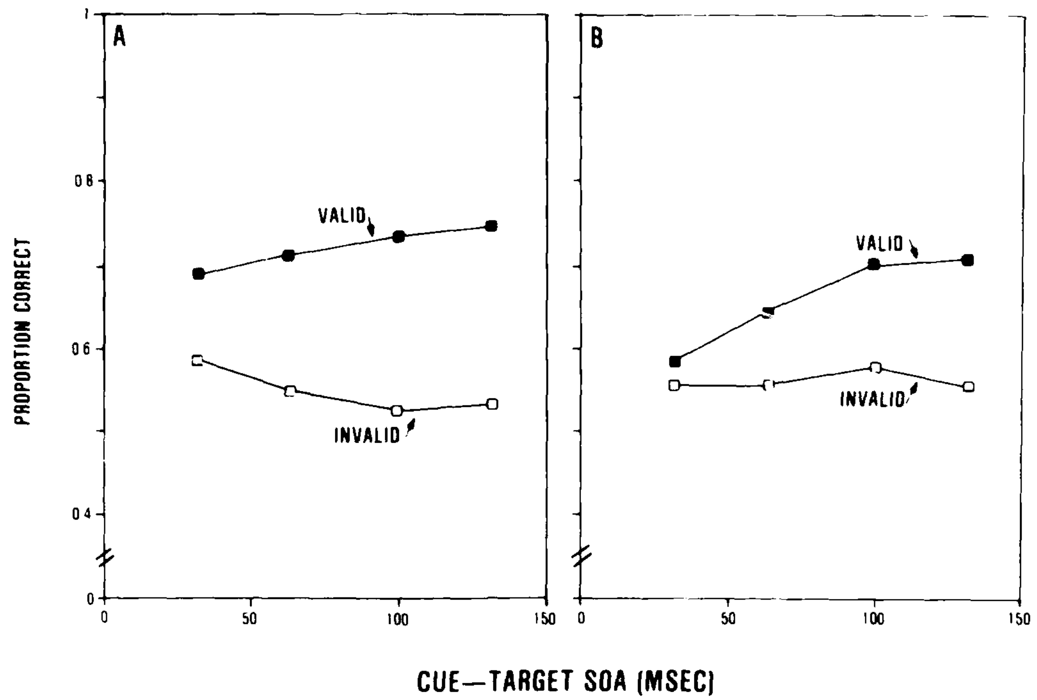


Figure 6. Proportion Correct as a Function of Cue-Target SOA in Experiment 2B. Mean of two durations of valid and invalid trials for naive observers. A: SLANTs; B: SIDEWAYS Ts.

There was a significant interaction of accuracy with location X stimulus type X target orientation (Experiment 2A: $\underline{X}^2[3] = 31.79$; Experiment 2B: $\underline{X}^2[3] = 50.70$, $\underline{p} < .0001$). Responses to SLANT targets right of fixation were most accurate in both Experiments 2A and 2B. However, as in Experiment 1, when the stimuli were Ts, order of accuracy varied as a function of target orientation. Right-oriented Ts received more correct responses when they were on the left, and left-oriented Ts received more correct responses when they were on the right.

IV. DISCUSSION

The main result is clear. Attention facilitates discrimination of Ts much more than discrimination of SLANTs. In Experiments 1, 2A, and 2B, the proportion of correct discriminations did not increase as much with a longer time between cue and target when the stimuli were SLANTs as when they were Ts. If one assumes that longer cue-target SOAs allow more time to allocate attention to the target area, then these results imply that orientation discrimination does not benefit as much from attention as does discrimination of line

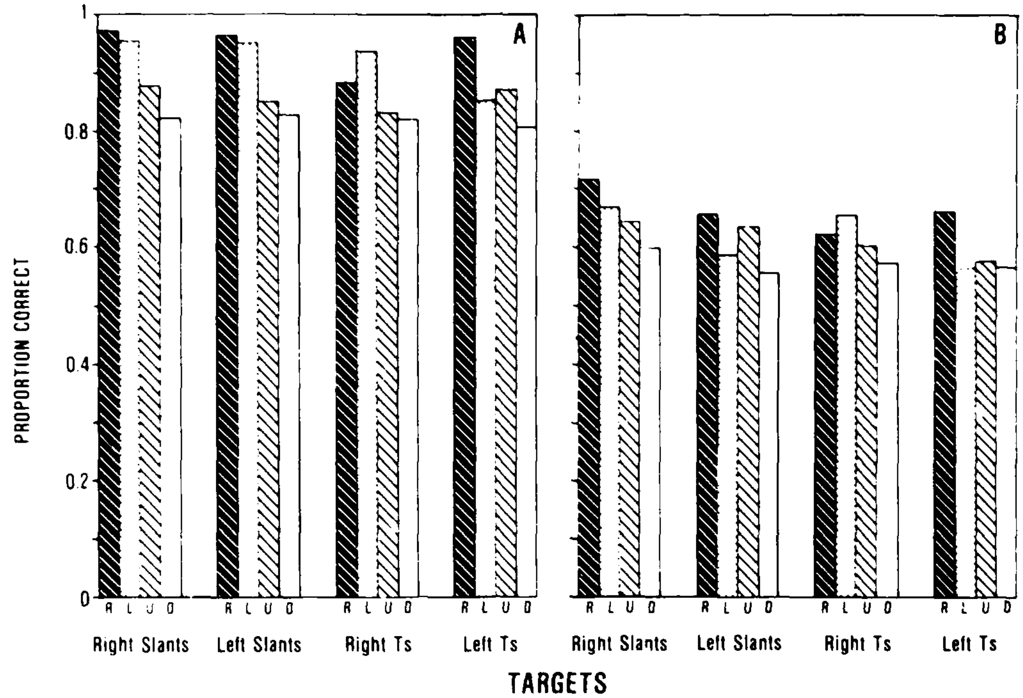


Figure 7. Proportion Correct as a Function of Location of Target in Experiment 2. Location was right (R), left (L), up (U), or down (D) for SLANTs that faced right or left and for Ts that faced right or left. A. Experienced observers in Experiment 2A. Standard deviation of the proportion < .01 for each bar. B. Naive observers in Experiment 2B. Standard deviation of the proportion < .02 for each bar.

arrangement. The benefit that does occur in discrimination of line orientation occurs in the first 50 msec. For discrimination of line arrangement, performance continues to improve with additional time to focus attention.

The differences between responses to the two types of stimuli were very strong. Not only were the results highly significant, but they were shown in each of the observers, they were independent of overall probability correct, and they occurred for each duration of stimulus presentation. In fact, it was possible to show a difference in the effects of attention on the two types of stimuli even when a number of factors that have previously been associated with differentiation of focused from global responses were not present. These include (a) semantic content (Broadbent, 1977; Burke, White, & Diaz, 1987); neither stimulus needed semantic interpretation; (b) detection vs discrimination (Sagi & Julesz, 1985a); discrimination was required for both sets of stimuli; and (c) amount of practice or experience in the task (e.g. LaBerge, 1981); although automatic detection of search targets can develop with practice, in these experiments discrimination of Ts was still greatly facilitated by attention after considerable practice. Improvement with practice occurred with both SLANTs and Ts, yet the difference between the size of the attention effect on SLANTs and Ts did not decrease over thousands of trials under consistent mapping conditions (Schneider & Shiffrin, 1977). There were no significant differences in the interactions between target type and cue-target SOA for early, middle, and late trials. Moreover, the same observers still showed this difference between responses to SLANTs and to Ts in subsequent trials in Experiment 2A even though only four cue-target SOAs were used.

Although the effect of location cueing was much larger for Ts than for SLANTs, there was, nevertheless, a significant early rise in the curve for the SLANT data. This could be related to a combination of several possible factors. First, the observers had to determine the location of the cue in order to know which of the four stimuli was the target. Variability on trials as to the time needed to make this determination could be responsible for the slope of the line for the first three cue-target SOAs.

It is also possible that when the SOA was very short, the observers sometimes failed to see the cue and therefore did not know which stimulus was the target. In fact, the observers reported that they occasionally did not see the cue. It is also possible that the cue actually masked the target on some of the short cue-target SOA trials.

Finally, it is possible that focal attention improved discrimination of the SLANTs as well as the Ts, but to a much lesser extent. Inasmuch as detection of simple light increment is facilitated by attention to the correct location (Posner, 1980; Posner & Cohen, 1984), it is possible that attention can both improve the visibility of the lines of a stimulus, and also improve the perception of the relative positions of line segments. Only the former contribution of attention would affect the SLANT data, whereas both aspects of attention would affect discrimination of the Ts. This former contribution of attention, improvement of the visibility of the lines, could be a separate process from the improvement for discrimination of Ts seen with longer SOAs.

Whatever the explanation for the slight improvement in performance in the SLANT condition, the large difference in the size of attention effects in SLANT vs T conditions is an interesting result that could be due to a number of theoretical possibilities. One conceivable explanation is that there is some inherent difference in the way that attention affects perception of oblique line segments as opposed to horizontal or vertical line segments, inasmuch as the the Ts were always oriented vertically and horizontally, whereas the SLANTs were oriented obliquely. There are data suggesting that the visual system operates differently in the perception of horizontal and vertical lines in comparison to the perception of oblique lines (Pettigrew, Nikara, & Bishop, 1968; Vogels & Orban, 1986). By analogy, attentional effects on discrimination of different types of stimuli could also vary as a function of line orientation.

A second potential explanation is the difference in illumination between the two types of targets. In order to closely equate proportion correct responses for the two targets, SLANTs consisted of only five pixels, whereas 24 pixels were used in each T. The equality of proportion correct was a necessary control for this experiment. The task was not testing discriminability of the two types of targets but rather, the effects of varying the time available for shift and focus of attention. There is no reason from previous research to think that luminance difference would affect the degree to which discrimination would be facilitated by attention.

Another possibility is suggested by the fact that the stimuli differ in the number of features, such as the number of line segments and the number of terminators. Perhaps more focus of attention is necessary for stimuli that consist of more line segments. This explanation is supported by the texture segregation experiments (Beck & Ambler, 1972; Julesz, 1981).

A fourth hypothesis is one that has been proposed in several models of visual information processing that differentiate between global, preattentive, parallel processes and focused, concentrated, serial processes (Neisser, 1967; Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977; Treisman & Gelade, 1980). That is, discrimination of SLANTs, based on line orientation differences, may be an automatic process that is made globally or preattentively, whereas discrimination of Ts, based on conjunction of line segments, is a controlled process that requires time to focus attention (Kahneman & Treisman, 1984). This interpretation of Experiment 1 is most consistent with a large segment of the literature.

The interpretation of these results to imply that orientation discrimination does not require focused attention does not conflict with the data of Sagi & Julesz (1985a, 1985b). These authors concluded from their research that discrimination of line orientation required a serial search or focused attention. However, in one condition, observers were asked to count a particular target orientation. In the other condition, they were asked to tell whether two or more lines differed in orientation, but not to tell the orientation. Thus, a comparison of two or more stimuli was required, and a decision as to "same" or "different" was made. This comparison introduced another step in the processing that may have required time and focused attention.

Data from Experiment 2, however, may not be consistent with the idea that orientation discrimination is a completely automatic process (Kahneman & Treisman, 1984), because there was a decrement in accuracy when a target was incorrectly cued. This was true when the stimuli were SLANTs as well as when the stimuli were Ts. The strong effect of invalid trials was not merely a function of observers who were "overtrained" on the valid task inasmuch as the observers who were initially started with 20% invalid trials showed the same effect.

The decrement in performance on invalid trials is consistent, however, with the concept of disengaging attention from a current focus of attention (Posner, Walker, Friedrich, & Rafal, 1984). LaBerge (1973) suggested that not only must attention be switched to a target, but attention must also be switched away from a previous target. More recently, Posner and his colleagues have proposed that orienting attention to a visual stimulus without eye movements can be considered in terms of three mental operations. It is necessary to first disengage attention from the current focus of attention, then move attention to a new stimulus, and finally engage attention on that stimulus (Posner et al., 1984). Although is is not possible to directly separate these components, the "disengage" operation can be inferred from the decrement in performance when attention is misdirected to an incorrect location. Thus, the decrement in accuracy on invalid trials in Experiment 2 could be representative of the time needed to disengage attention from the correct location. It is even possible that the small facilitation of attention in discrimination of SLANTs that was found with short SOAs in Experiment 1 is due in part to the necessity of disengaging attention from the fixation point. Although, the disengage process was originally defined in the context of invalid trials, it may also be necessary to disengage attention from the fixation point on valid and invalid trials in order to know the appropriate location for the target.

In distinction to these effects, it could be proposed that the large increment in accuracy that occurs with longer cue-target SOAs in discrimination of Ts is representative of movement and engagement of attention, a later accumulation of attentional effects that are needed for discriminations based on arrangement of lines, but not for discriminations based on line orientation.

The processes of disengage, shift, and engage may be similar to processes suggested by animal research (Cheal, 1981, 1983, 1984) and in research on humans with disordered attention (Mirsky, 1987). Attentional processes that include the ability to select or focus on a stimulus, to maintain or sustain attention on the stimulus, and to shift attention to another stimulus have been separated by psychopharmacological manipulations, brain lesions, neuroelectrophysiology, and human attentional disorders.

A number of additional experiments will be required to unravel the questions that arise from the present experiments. One series of experiments is needed to test the alternative explanations for the difference between the effect of attention on discrimination of SLANTS vs discrimination of Ts. Another series of experiments will be needed to further investigate the decrement associated with incorrectly cued trials for an otherwise "automatic" target.

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