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Performance under Dichoptic versus Binocular Viewing Conditions: Effects of Attention and Task Requirements

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Three experiments investigated subjects' ability to allocate attention and cope with task requirements under dichoptic versus binocular viewing conditions. Experiments 1 and 2 employed a target detection task in compound and noncompound stimuli, and Experiment 3 employed a relative-proximity judgment task. The tasks were performed in a focused attention condition in which subjects had to attend to the stimulus presented to one eye or field (under dichoptic and binocular viewing conditions, respectively) while ignoring the stimulus presented to the other eye or field, and in a divided attention condition in which subjects had to attend to the stimuli presented to both eyes or fields. Subjects' performance was affected by the interaction of attention conditions with task requirements, but it was generally the same under dichoptic and binocular viewing conditions. The more dependent the task was on finer discrimination, the more performance was impaired by divided attention. These results suggest that at least with discrete tasks and relatively short exposure durations, performance when each eye is presented with a separate stimulus is the same as when the entire field of stimulation is viewed by both eyes.

INTRODUCTION

The use of single-eye helmet-mounted displays in operational environments (eg., when piloting a helicopter in night flights with a forward-looking infrared display) raises theoretical and applied questions concerning the ability of humans to cope with task requirements under dichoptic viewing conditions, in which each eye is presented with a separate visual array.

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In normal vision we view the world binocularly, with both eyes. Because human eyes are located in the front of the head, they look at much the same region of the visual space, providing an overlapping binocular field. Only near the margins of the visual field do the two eyes provide exclusive monocular coverage. Within the region of binocular overlap the two eyes view objects and scenes from slightly different vantage points because of the lateral separation between them. Using this binocular disparity information humans are able to make fine depth judgments. When the two eyes receive different inputs, binocular rivalry may arise: one input becomes perceptually dominant while the other is suppressed, and alternation in perceptual dominance may occur.

Dichoptic viewing has been widely used in research designed to understand the cooperation between the two eyes in normal vision. This research has focused on revealing the conditions under which the inputs from the two eyes fuse into a single percept, sometimes producing stereopsis, and the conditions under which binocular rivalry arises. A central question has been whether the mechanisms responsible for stereopsis and binocular rivalry are central or peripheral (see Arditi, 1986; Long, 1979; Walker, 1978; and Wolfe, 1986, for extensive reviews).

A single-eye helmet-mounted display presents a novel experimental challenge in which previous research can serve only to highlight important variables and set some general constraints. Although stereopsis and binocular rivalry are generally relevant to the issue at hand, it is important to recognize that the major questions raised by the single-eye display are different. Operators in such situations often attempt to treat the two eye fields as separate information channels rather than fuse information from both eyes into a single percept. From a human factors point of view, the main interest is human performance under dichoptic viewing conditions and the processes involved in this performance, rather than the use of dichoptic viewing as a paradigm for studying elementary visual processes. Consequently our use of the term *dichoptic* is more general than the one usually used in the literature. The term *dichoptic* most often refers to a situation in which different stimuli are presented to corresponding loci in the two eyes. We use it to refer to all cases in which different stimuli are presented simultaneously to the two eyes, including a situation in which only one eye is stimulated at any given location. (According to the usual use of the term *dichoptic,* this latter situation may be considered a simultaneous monocular presentation.)

There are also differences between the types of task variables that are of most interest to human factors researchers and those that have been prevalent in the research of elementary visual processes. Stereopsis and rivalry experiments have typically used simple psychophysical tasks (e.g., detection of luminance changes). It is difficult to connect the findings of that research to the tasks relevant to operational situations, such as detection, identification, and evaluation of relevant information.

Our main interest is in assessing humans' ability to allocate attention and cope with task requirements under dichoptic viewing conditions, as compared with performance under normal viewing conditions. In a review of the literature we were able to find only two studies of dichoptic viewing that were conducted with a similar perspective. In one experiment Schwank (1976) reported that performance under dichoptic viewing conditions was significantly inferior to performance under binocular viewing conditions in processing independent signals. However, Neisser and Becklen (1975) reported no difference in performance when two game episodes were presented dichoptically and when both were presented binocularly, superimposed. The binocular condition used by Neisser and Becklen was not exactly analogous to natural binocular viewing because we rarely view two scenes superimposed. With regard to Schwank's report, his findings may be limited to the particular task used.

This is the first report of an ongoing research effort to study performance under dichoptic viewing conditions. In three experiments subjects were briefly shown a display containing two stimuli and were required to perform a designated task under two attention conditions: in the focused attention condition subjects had to attend to one stimulus while ignoring the other; in the divided attention condition subjects had to attend to both stimuli. In binocular viewing the two stimuli were viewed by both eyes (see Figure 1), simulating normal viewing in which the two eyes view a display containing two stimuli positioned side by side. In dichoptic viewing each eye was presented with a separate stimulus.

These experiments were specifically aimed at answering two questions. First, does dichoptic presentation change the difficulty of monitoring one stimulus and ignoring another? Second, does it change the difficulty of monitoring two stimuli? The tasks selected are analogous to tasks in operational situations: identification of global/local information, letter identification, and judgments of relationships between objects.

EXPERIMENT 1

The processing of global and local aspects of a single visual object has been studied, under normal viewing conditions, using compound stimuli (e.g., Kimchi, 1988; Kimchi and Palmer, 1985; Miller, 1981; Navon, 1977, 1981; Pomerantz, 1983). Experiment 1 examined the detection of global and local targets under dichoptic and binocular viewing conditions. Subjects were briefly shown a display containing two compound letters, and their task was to search for a target letter at the global level, local level, or both levels (see sections on stimuli and design). Subjects were to search for the target either in one stimulus while ignoring the other (focused attention) or in the two stimuli (divided attention).

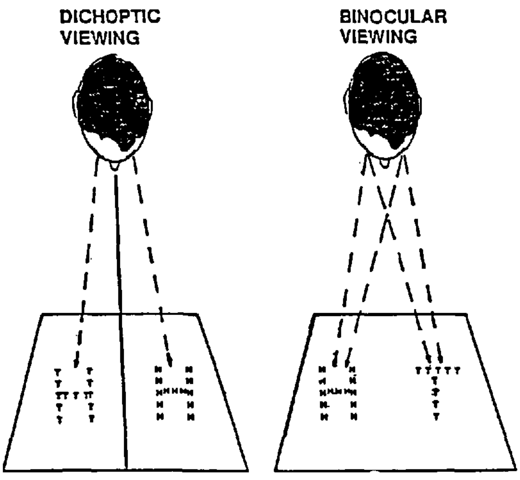

Figure 1. *The binocular and dichoptic viewing conditions.*

Method

Subjects. Twenty-four male students age 23 to 30 years old were paid for participation in the experiment. All had normal vision. Twelve were tested under dichoptic viewing conditions and 12 under binocular conditions.

Apparatus. Two microprocessors (IBM AT) were programmed to operate in synchrony to provide two independent images. A special horizontal T-shaped wooden tunnel was constructed. The two computer monitors were placed facing each other on the two sides of the T head. Images were projected via two reflective mirrors, each positioned at an angle of 45 deg relative to subjects' eyes and the respected computer monitor (see Figure 2). The two images were matched for brightness and position. The subject's head was fixed with a chin rest. With this arrangement subjects saw what appeared to be a single display containing two stimuli positioned side by side. Subjects' eyes were at an optical distance of 45 cm from the display. The two stimuli were an average of 7.6 deg of visual angle apart (measured between the centers of the two stimuli, and calibrated individually for each subject). Under the dichoptic viewing condition a partition ensured the separation between the two eyes so that subjects

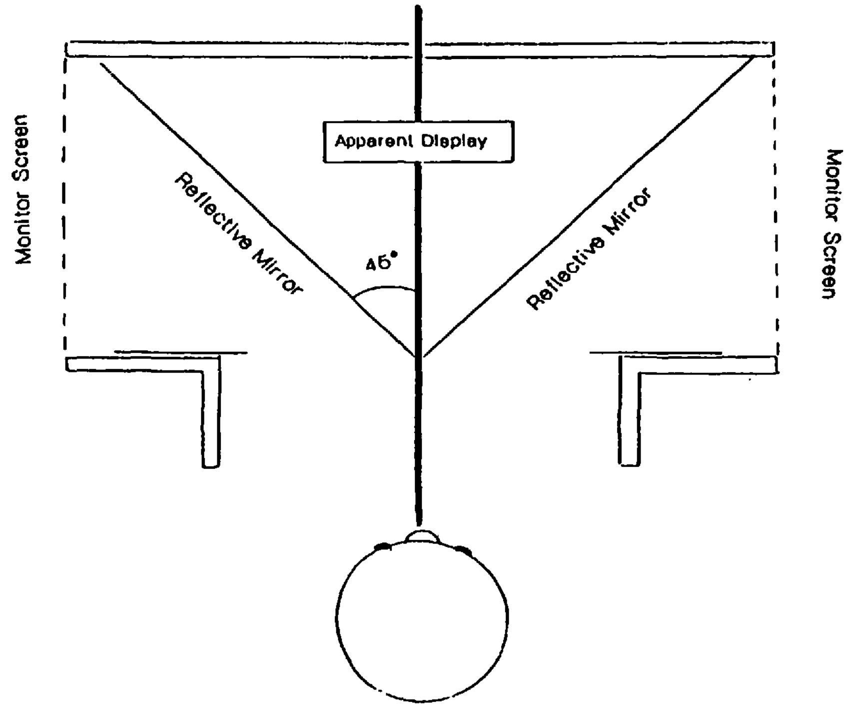

Figure 2. *Schematic top view of the optical arrangement used. There was no partition in the binocular viewing condition.*

saw one stimulus with their right eye and the other stimulus with their left eye. Under the binocular viewing condition no partition was used, so subjects saw the two stimuli with both eyes. The actual optical arrangement was not visible to the subject. Two keys on the IBM keyboard were used as response keys.

Stimuli. The stimuli used were the letters *H* and *T* composed of small *H*'s or small *T*'s, making up a set of four possible stimuli: two *congruent* stimuli (*H* composed of *H*'s, and *T* composed of *T*'s) and two *incongruent* stimuli (*H* composed of *T*'s, and *T* composed of *H*'s). The set of stimuli is presented in Figure 3. The target letter was *H*. The large letter subtended 2.5 deg of visual angle in width and 3.2 deg in height. The small letter subtended 0.25 deg in width and 0.5 deg in height. The visual stimuli were white on a black background.

Design. Subjects in each viewing situation performed three tasks (global directed, local directed, both levels) in two attention conditions (focused, divided). In the *global-directed* task subjects were instructed to search for the target at the global level of the stimulus. In the *local-directed* task subjects were instructed to search for the target at the local level. Subjects were asked to respond positively ("yes") if the target letter was present at the designated level and negatively ("no") if it was not present at that level. In the *both-levels* task subjects had to search for the tar-

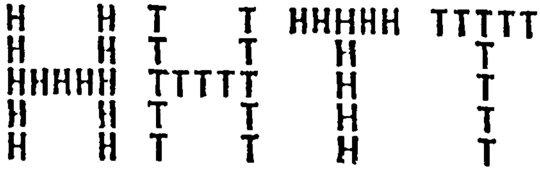

Figure 3. *The stimulus set used in Experiment 1.*

get at both levels and were asked to make a positive response if the target letter appeared at the local, global, or both levels and a negative response otherwise. The three tasks were administered in different groups of blocks, and their order was counterbalanced across subjects.

Subjects performed each of these tasks in a *focused attention* condition, in which they were required to attend to the stimulus presented to one eye or field (i.e., the relevant stimulus) and ignore the stimulus presented to the other eye or field (i.e., the irrelevant stimulus), and in a *divided attention* condition, in which they were required to attend to both eyes or fields and perform the designated task. The two attention conditions were administered in two different sessions on different days, and their order was counterbalanced across subjects.

The focused attention task included 900 experimental trials: 288 trials in four blocks of 72 trials each of the global-directed search task, 288 trials in four blocks of 72 trials each of the local-directed search task, and 324 trials in four blocks of 82 trials each of the both-levels search task. Half of the trials of each task were positive ("yes" response trials) and the other half were negative ("no" response trials). In the global- and local-directed tasks half of the relevant stimuli of each response type were *congruent stimuli*, and half were *incongruent stimuli*. In the both-levels task a third of the relevant stimuli of the positive response trials contained a target at the global level only (*incongruent global*), a third contained a target at the local level only (*incongruent local*), and a third contained a target at both levels (*congruent*).

The information presented to the irrelevant eye or field was one of three types: a *compatible* type, in which the irrelevant stimulus was compatible with the relevant one in terms of potential response (i.e., a potential "yes" response in the relevant and in the irrelevant eye or field, or a potential "no" response in the relevant and in the irrelevant eye or field); an *incompatible* type, in which the irrelevant stimulus was incompatible with the relevant one in terms of potential response (i.e., a potential "yes" response in the relevant eye or field and a potential "no" response in the irrelevant eye or field, or vice versa); and a control condition in which *no stimulus* was presented to the irrelevant eye or field. These three conditions were completely crossed with all the aforementioned types of relevant stimuli.

The divided attention condition included 864 experimental trials: 288 trials in four blocks of 72 trials of each task. Half of the trials of each task were positive (i.e., a target was present in at least one stimulus), and half were negative (no target was present in the display). In a third of the positive trials of each of the tasks the two stimuli in the display were compatible (i.e., both stimuli contained a target), in a third they were incompatible (i.e., one stimulus contained a target and the other stimulus contained no target), and in a third the display contained only one stimulus (i.e., a stimulus was presented only to one eye or field). In half of the negative trials of each task the display contained compatible stimuli (i.e., both stimuli contained no target), and in the other half the display contained only one stimulus.

In each attention condition, at the start of each task subjects received 36 practice trials. In addition, the first two trials of each block were warm-up trials and were not included in the analyses.

Procedure. Subjects participated individually. The finger-aiming test was used to determine eye dominance. At the start of each experimental session subjects were familiarized with the stimulus set and instructed in regard to the attention condition and the designated task. The subjects were instructed to make their responses with the index fingers of their left and right hands as quickly as possible while making as few errors as possible. Half of the subjects were instructed to press the leftmost key for a "yes" response and the rightmost key for a "no" response; the other half were given the opposite instruction.

The sequence of events for each trial was as follows. First two crosses appeared for 500 ms indicating the locations of the stimuli to be presented. After a 500 ms interval the stimuli appeared for 150 ms; then a mask was displayed in the same location as the stimulus. The mask remained on until the subject responded or until the 3000 ms interval allowed for a response had elapsed. Then a visual feedback display was presented for 300 ms. There was a 1200 ms intertrial interval. In the focused attention condition an auditory signal of two levels (200 Hz and 2000 Hz) was used to direct attention to the relevant eye or field (left or right). The auditory signal was given through earphones to both ears simultaneously with display of the cross indicators. To detect blinking, eye movements were monitored by four chromosilver electrodes that were placed above and below subjects' eyes. The electrodes were connected to a Nikon-Kohnen polygraph, and electrooculogram (EOG) records were monitored on line by the experimenter for unusual blinks and eye movements. Each attention condition session lasted about 2 h.

Results

Blinking was detected in 0.42% of the trials. Responses on these trials were eliminated from the following analyses. Mean reaction times (RTs) and percentage error rates (ERs), averaged across response types, for the three tasks in each attention condition under binocular and dichoptic viewing conditions are presented in Figure 4. The initial analysis of the data of the present experiment as well as those of Experiments 2 and 3 included the factor of eye dominance. No significant effects involving this factor were obtained, so the following analyses were collapsed over this factor. We started by examining the effects of viewing, attentional instructions, and task requirements on performance. We then proceeded with further, more detailed analyses in order to get a closer look at subjects' performance under focused and divided attention, and on the tasks involved. Because of the different natures of the directed and the nondirected (both level) tasks, and because previous findings showed that these two types of tasks may yield different patterns of results (e.g., Miller, 1981), two separate analyses were performed: one analysis involved the two directed tasks, and the second analysis involved the both-levels task. All the analyses of variance (ANOVAs) performed on the data of Experiments 1 and 2 treated viewing as a between-subject factor and all other relevant factors as within-subject factors.

Global- and local-directed tasks. A four-factor analysis of variance (ANOVA; Viewing × Attention × Task × Response Type) indicated significant effects of attention conditions and tasks (all p's < 0.01 for RTs and ERs) and no significant effect of viewing ($F < 1$ for RTs and ERs). Negative responses were slower than positive responses ($p < 0.0001$) but not less accurate. Tasks interacted significantly with attention conditions, $F(1,22) = 40.30$, $p < 0.0001$ for RTs; $F(1,22) = 61.65$, $p < 0.0001$ for ERs. A breakdown of this interaction revealed that performance on the local-directed task was faster and more accurate in the focused than in the divided attention condition, $F(1,22) = 19.98$, $p < 0.0002$ for RTs; $F(1,22) = 58.85$, $p < 0.0001$ for ERs. Attention conditions had no effect on the performance of the global-directed task. Also, performance on the global-directed task was faster and more accurate than performance on the local-directed task only in the divided attention condition. $F(1,22) = 66.22$, $p < 0.0001$ for RTs; $F(1,22) = 64.90$, $p < 0.0001$ for ERs.

The only significant interaction involving viewing was between viewing, attention conditions, and tasks for RTs only, $F(1,22) = 4.47$, $p < 0.05$; $F < 1$ for ERs. A breakdown of this interaction revealed that the differential effect of attention conditions on global and local detection was present under both viewing conditions, $F(1,11) = 8.71$, $p < 0.02$; $F(1,11) = 36.87$, $p < 0.0001$, for dichoptic and binocular viewing, respectively, but the effect was somewhat greater under binocular viewing conditions than under dichoptic ones (see Figure 4).

Both-levels task. A three-factor ANOVA (Viewing × Attention × Response Type)

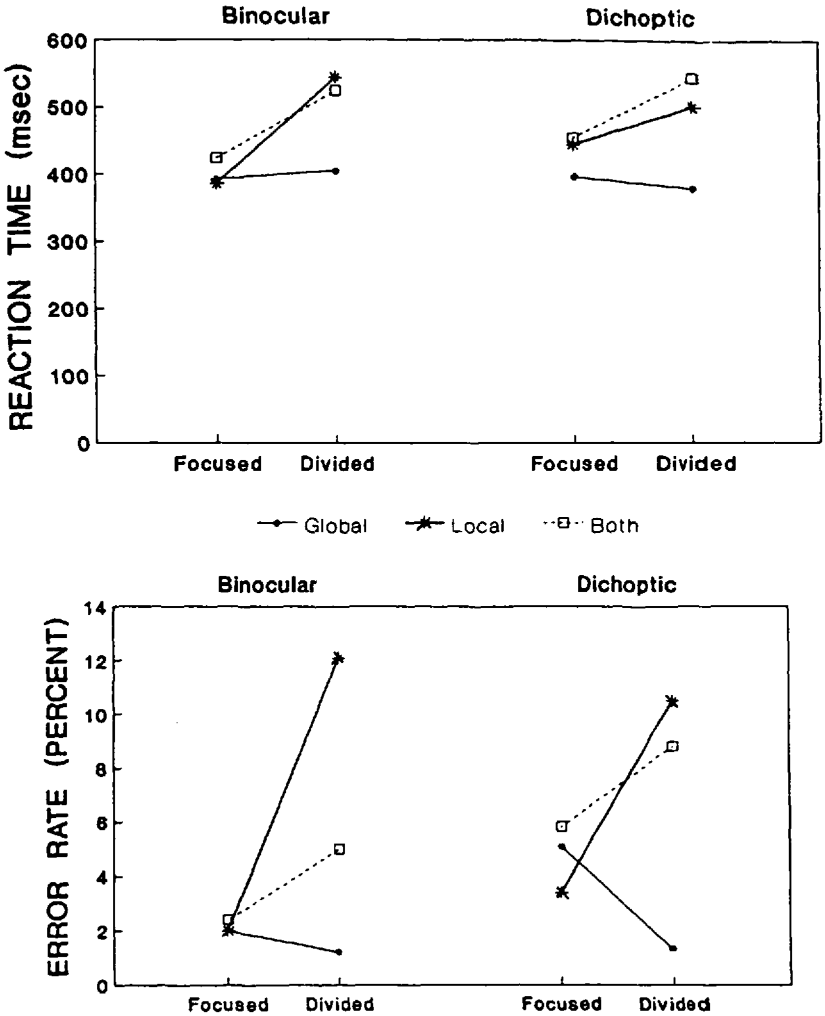

Figure 4. *Mean reaction times and error rates for each task as a function of attention and viewing conditions in Experiment 1.*

indicated no significant effect of viewing, $F < 1$ for RTs; $F(1,22) = 3.47$, $p > 0.076$ for ERs, and no interaction between viewing and attention, $F < 1$. Performance under the divided attention condition was slower than performance under the focused attention condition, $F(1,22) = 15.97$, $p < 0.0006$ for RTs; $F(1,22) = 9.40$, $p < 0.006$ for ERs. Negative responses were slower than positive responses ($p < 0.05$), and a larger effect was noted for the divided attention condition than for the focused attention condition, as indicated by the interaction between attention conditions and response types, $F(1,22) = 21.34$, $p < 0.0001$.

Focused attention: The effect of irrelevant stimulus. A three-factor ANOVA (Viewing × Task × Irrelevant Stimulus) performed on the data of the two directed tasks indicated a significant effect of irrelevant stimulus, $F(2,44) = 8.47$, $p < 0.0008$ for RTs; $F(2,44) = 3.49$, $p < 0.04$ for ERs. Irrelevant stimulus did not interact with viewing ($F < 1$ for both RTs and ERs) or with task. Mean RTs for compatible, incompatible, and no irrelevant stimulus were 411, 413, and 393 ms, respectively. The respective means for percentage errors were 2.6%, 3.1%, and 2.2%. Pairwise comparisons using Duncan's procedure revealed that reaction times were faster in the absence of irrelevant stimulus than in its presence. Error rates were higher when the irrelevant stimulus was incompatible with the relevant one than when no irrelevant stimulus was present.

Analysis of the data of the both-levels task by a two-factor ANOVA (Viewing × Irrelevant Stimulus) indicated a significant effect of irrelevant stimulus for RTs only, $F(2,44) = 3.62$, $p < 0.04$. Irrelevant stimulus did not interact with viewing, $F(2,44) = 1.39$, $p > 0.26$. Mean RTs for compatible, incompatible, and no irrelevant stimulus were 437, 450, and 429 ms, respectively. Reaction times were faster in the absence of irrelevant stimuli than in the presence of incompatible irrelevant stimuli.

Divided attention: The effect of stimuli's compatibility. The data of the two directed tasks (positive trials) were analyzed by a three-factor ANOVA (Viewing × Task × Compatibility). The analysis indicated a significant effect of compatibility, $F(2,44) = 42.92$, $p < 0.0001$ for RTs; $F(2,44) = 35.37$, $p < 0.0001$ for ERs, a significant interaction between tasks and compatibility, $F(2,44) = 4.05$, $p < 0.03$ for RTs; $F(2,44) = 27.35$, $p < 0.0001$ for ERs, and no significant interaction between compatibility and viewing, $F(2,44) = 2.33$, $p > 0.11$, $F(2,44) = 1.5$, $p > 0.23$, for RTs and ERs, respectively. The three-way interaction between viewing, tasks, and compatibility was not significant ($F < 1$). Mean RTs for compatible, incompatible, and one-stimulus display were 310, 359, and 347 ms, respectively, for the global-directed task and 394, 477, and 468 ms, respectively, for the local-directed task. The respective means for percentage errors were 0.5%, 2.8%, and 1.15% for the global-directed task and 1.2%, 22.4%, and 7.8% for the local-directed task. Duncan's pairwise comparisons revealed that RTs were faster with compatible stimuli than with either incompatible or one-stimulus presentations. Incompatible stimuli produced more errors than did compatible and one-stimulus presentations. These effects were larger for the local-directed task than for the global-directed task as indicated by the interaction between compatibility and tasks.

The two-factor ANOVA (Viewing × Compatibility) performed on the data of the both-levels task indicated a significant effect of compatibility, $F(2,44) = 19.37$, $p < 0.0001$ for RTs; $F(2,44) = 9.51$, $p < 0.0004$ for ERs, and no significant interaction between viewing and compatibility ($F < 1$). Mean RTs for compatible, incompatible, and one-stimulus display were 430, 503, and 464 ms, respectively. The respective means for percentage errors were 2.9%, 13.3%, and 7.6%. Compatible stimuli produced faster and more accurate responses than did incompatible and one-stimulus presentations.

Congruity effects. Mean RTs and ERs for congruent and incongruent stimuli in positive trials of the directed tasks under focused attention were submitted to a three-factor ANOVA (Task × Congruity × Viewing), which indicated a significant effect of congruity for RTs, $F(1,22) = 15.39, p < 0.0007$, but not for ERs. No interaction effect was significant. Mean RTs for congruent and incongruent stimuli were 357 and 385 ms, respectively. Under both viewing conditions, a target was detected faster in a congruent stimulus than in an incongruent one, and mutual interference was noted between the global and the local levels.

A two-factor ANOVA (Congruity × Viewing) performed on the data of the both-level task indicated a significant effect of congruity for RTs, $F(2,44) = 16.36, p < 0.0001$, but not for ERs, and no significant interaction between viewing and congruity ($F < 1$). Mean RTs for congruent, incongruent-global, and incongruent-local stimuli were 374, 434, and 454 ms, respectively. Pairwise comparisons using Duncan's procedure revealed a significant difference between congruent and incongruent stimuli but not between incongruent stimuli in which the target was located at the global level and those in which the target was located at the local level.

The effect of directing attention to a stimulus' level. In order to evaluate the effect of directing attention to a level of a stimulus, the data of the directed tasks (incongruent stimuli) and those of the both-levels task (incongruent stimuli) were submitted to a three-factor ANOVA. The factors were viewing condition, task (directed, both-levels), and target (global, local). The analysis indicated a significant effect of tasks for both RTs, $F(1,22) = 18.31, p < 0.0003$, and ERs, $F(1,22) = 4.33, p < 0.05$. No other main effect or interaction was significant. Under both viewing conditions global targets were located faster (by an average of 85 ms) and more accurately (by an average of 2.9%) in the global-directed task (incongruent stimulus) than in the corresponding both-levels task (global target only), and local targets were located faster (by an average of 90 ms) and more accurately (by an average of 5%) in the local-directed task (incongruent stimulus) than in the corresponding both-levels task (local target only).

Discussion

The results of Experiment 1 show that subjects' ability to allocate attention and to perform task requirements under the dichoptic viewing condition was generally not inferior to their ability to do so under binocular viewing.

Performance in the focused attention condition was somewhat slower and less accurate in the presence of irrelevant stimuli than in their absence, but the effect of irrelevant stimulus was small (averaged 19 ms and 0.9% in RTs and ERs, respectively) and did not differ under the two viewing conditions. These results suggest that subjects' ability to focus on one stimulus while ignoring another when the two eyes viewed the relevant stimulus (binocular viewing) was equal to that when one eye viewed the relevant stimulus and the other eye viewed the irrelevant one (dichoptic viewing).

Performance in the divided attention condition was also the same under the two viewing conditions. Subjects responded faster in the presence of redundant (compatible) information, and incompatibility between the two stimuli produced lower accuracy rates, mainly for the local-directed task. Thus monitoring two stimuli viewed by the two eyes (binocular viewing) produced the same pattern of results as did monitoring two stimuli, each viewed by a separate eye (dichoptic viewing).

Performance on the tasks involved was affected mainly by attention conditions, rather than by viewing conditions. Under both viewing conditions the global-directed subjects were equally likely to detect a target, regardless of whether they monitored one stimulus or two stimuli. However, the local-directed subjects were slower and less accurate under the divided attention condition than under the focused attention condition. The cost in speed of processing attributable to the requirement to monitor two stimuli was somewhat higher under the binocular than the dichoptic viewing condition. This interaction effect may suggest the use of different strategies under the two viewing conditions, as we suggested elsewhere (Kimchi, Rubin, Gopher, and Raij, 1989). However, any such interpretation would be highly speculative because the effect was small, did not replicate in the next experiment, and was not found with the both-levels task, which was also affected by the requirement to divide attention.

The differential effect of the attention conditions on global and local detection may be attributable to a difference in allocation of attention. In the focused attention condition subjects could allocate attention to a certain area because they had advance knowledge about the location of the relevant stimulus. In the divided attention condition, however, it is more likely that attention was distributed over the entire field. Models of visual attention suggest a trade-off between the size of the visual field over which attention is distributed and its resolution (e.g., Eriksen and Yeh, 1985). Because local detection is more dependent on higher resolution than is global detection, distributing attention over the visual field is more likely to impair local detection than global detection.

The differential effect of distributed attention on global and local detection was also demonstrated by Lamb and Robertson (1988). They found that uncertainty about the spatial location of the stimulus (which presumably is a condition of distributed attention) impaired local detection, even for stimuli presented at fixation, but had no effect on global detection. It should be noted, however, that the effect seen in the present experiment can also be attributable to visual acuity. In the focused attention condition subjects were likely to fixate their eyes on the relevant stimulus. Consequently some local letters were viewed foveally, and the performance could benefit from the greater acuity at the fovea. The absence of an advantage for global detection in the focused attention condition—either in speed of processing or in interference effects—for both the directed and the nondirected tasks is also consistent with this account. In the divided attention condition at least some of the local letters, if not all, were viewed peripherally (depending on whether subjects chose to fixate on one stimulus, so that the other stimulus was viewed peripherally, or to fixate on imaginary central point, so that both stimuli were viewed peripherally). Because acuity decreases with eccentricity, peripheral viewing is more likely to impair local detection than global detection (e.g., Pomerantz, 1983).

Searching for a target in two simultaneously presented stimuli had a differential effect on global and local detection. No such effect was observed when subjects searched for a target in two levels of a single compound stimulus. Performance on the both-levels task showed that a target was located at the same speed whether it occurred at the global or local level. Furthermore, directing attention to the level at which the target appeared had a symmetrical facilitatory effect on global and local detection. These findings are consistent with those of Hoffman (1980) and Kinchla, Solis-Macias, and Hoffman (1983). To the extent that the effect of the attention conditions is mediated by an attentional mechanism, these results suggest that allocating attention to stimuli in the visual field and allocating attention to levels of a single stimulus may involve different mechanisms. Focusing attention on a level of a stimulus, unlike dividing attention between the levels, allows a selection of an optimal strategy for the designated level; for instance, tuning to a defined range of spatial frequencies may improve performance at that level (see also Kinchla et al., 1983). However, focusing on one stimulus (or a spatial location) in the visual field and dividing attention between two simultaneously presented stimuli (or two spatial locations) may involve different distributions of attention over the visual field, as discussed earlier.

EXPERIMENT 2

One of the findings of Experiment 1 was the differential sensitivity of global and the local detection to attention conditions. This finding can be attributed to the relative size of the global and local letters, to the different levels that the global and local letters constituted in the compound stimulus, or to both. Experiment 2 was designed to examine the relative effects of size and levels in the processing of compound stimuli of the kind used in Experiment 1 and to reexamine attention allocation and task performance under binocular and dichoptic viewing conditions.

Method

Subjects. Sixteen male students age 22 to 28 years old were paid for participation in the experiment. Eight were tested under dichoptic viewing conditions, and 8 were tested under binocular viewing conditions. None had participated in the previous experiment, and all had normal vision.

Stimuli. The stimuli used were the letters *H* and *T*, either small or large, compound or noncompound, making up a set of eight possible stimuli of four types: Two *large* (noncompound) stimuli (*H* and *T*), two *small* (noncompound) stimuli (*H* and *T*), two *global* (large compound) stimuli (*H* composed of *I*'s and *T* composed of I's), and two *local* (small compound) stimuli (small *H*'s making up a larger *I* and small *T*'s making up a larger *I*). The set of stimuli is presented in Figure 5. The target letter was *H*. The size of the letters was identical to their size in Experiment 1. The large letter was the same size as the global letter, and the small letter was the same

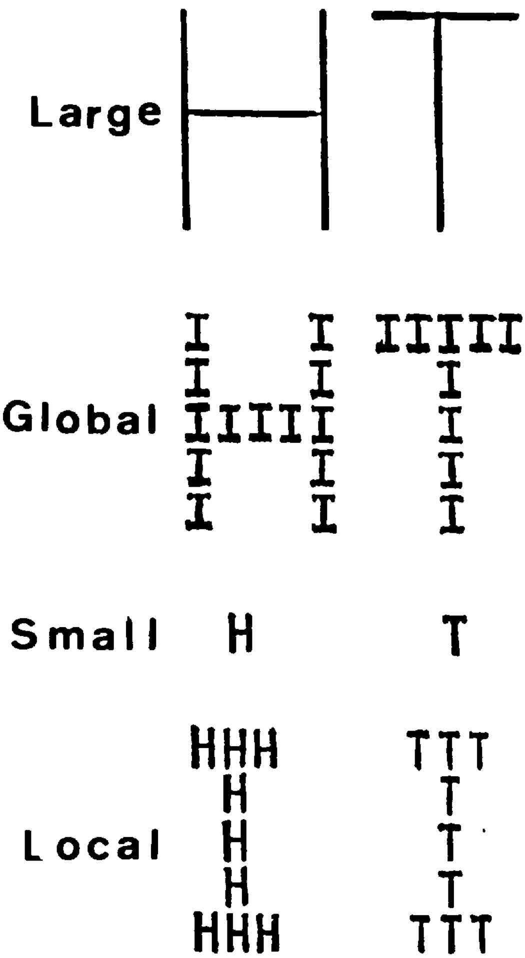

Figure 5. *The stimulus set used in Experiment 2.*

size as the local letter. A single local letter was presented at fixation.

Design. A yes-no detection task, identical to the one in Experiment 1, was used. The experiment employed a mixed five-factor design: viewing condition (binocular, dichoptic), attention condition (focused, divided), stimulus size (large, small), stimulus structure (compound, noncompound), and response type (positive, negative). The two attention conditions were administered in different sessions, and their order was counterbalanced across subjects. The four combinations of stimulus size and stimulus structure were administered in different blocks within each attention condition, and their order was counterbalanced across subjects.

The focused attention condition included 384 experimental trials in four blocks of 96 trials each. Half the trials in each block were positive, and half were negative. The information presented to the irrelevant eye or field was one of the three types described in Experiment 1.

The divided attention condition included 384 experimental trials in four blocks of 96 trials each. Half the trials in each block were positive, and half were negative. The positive trials included three types of presentations (compatible, incompatible, one-stimulus), and the negative trials included two types of presentations (compatible, one-stimulus), as in Experiment 1.

In each attention condition, at the start of each task subjects received 36 practice trials. In addition, the first two trials of each block were warm-up trials and were not included in the analyses.

Apparatus and procedure. The apparatus and procedure were the same as those of Experiment 1.

Results

Blinking was detected on 0.37% of the trials. Response on these trials were eliminated from the following analyses. Mean RTs and ERs, averaged across response type, for the four types of stimuli in each attention condition under binocular and dichoptic viewing conditions are presented in Figure 6. The data were first analyzed by a five-factor ANOVA (Viewing × Attention × Stimulus Size × Stimulus Structure × Response Type). The analysis indicated significant effects of attention condition, stimulus size (all *p*s < 0.001 for both RTs and ERs), and response type (for RTs only, $p < 0.0001$). There was no significant effect of viewing ($F < 1$ for RTs and ERs), no significant effect of stimulus structure, and no significant interactions involving these factors. Attention conditions interacted with stimulus size, $F(1,14) = 68.89, p < 0.0001$ for RTs; $F(1,14) = 53.98$, $p < 0.0001$ for ERs. A breakdown of this interaction revealed that small/local letters were detected faster and more accurately in the focused attention condition than in the divided attention condition, $F(1,14) = 36.79, p < 0.0001$ for RTs; $F(1,14) = 78.9$, $p < 0.0001$ for ERs, whereas detection of large letters, either compound or noncompound, was not affected by attention condition. Also, large/global letters were detected faster and more accurately than were small/local letters in the divided attention condition only, $F(1,14) = 60.28, p < 0.0001$ for RTs; $F(1,14) = 57.26$, $p < 0.0001$ for ERs.

Focused attention: The effect of irrelevant stimulus. A four-factor ANOVA (Viewing × Stimulus Size × Stimulus Structure × Irrelevant Stimulus) indicated a significant effect of irrelevant stimulus for RTs only, $F(2,28) = 6.24$, $p < 0.0057$; $F < 1$ for ERs. Irrelevant stimulus did not interact with viewing ($F < 1$ for both RTs and ERs), stimulus size, or stimulus structure. Mean RTs for compatible, incompatible, and no irrelevant stimulus were 369, 369, and 354 ms, respectively. Duncan's pairwise comparisons revealed that reaction times were faster in the absence of irrelevant

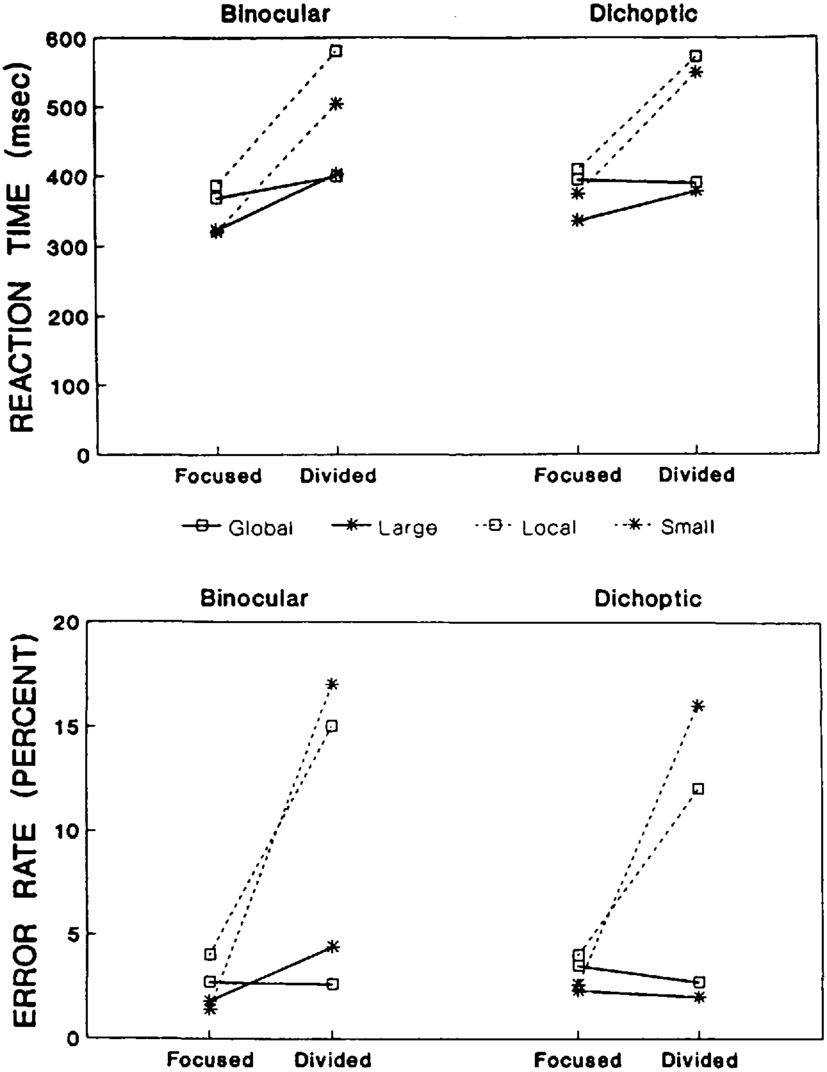

Figure 6. *Mean reaction times and error rates for each task as a function of attention and viewing conditions in Experiment 2.*

stimuli than in their presence, but the compatibility or incompatibility of the irrelevant stimulus had no effect on performance.

Divided attention: The effect of stimuli's compatibility. A four-factor ANOVA (Viewing × Stimulus Size × Stimulus Structure × Compatibility) indicated a significant effect of compatibility, $F(2,28) = 57.77$, $p < 0.0001$ for RTs; $F(2,28) = 23.36$, $p < 0.0001$ for ERs, and a significant interaction between compatibility and stimulus size, $F(2,28) = 6.3$, $p < 0.0055$ for RTs; $F(2,28) = 14.53$, $p < 0.0001$ for ERs. Compatibility did not interact with viewing, $F(2,28) = 1.82$, $p > 0.2$ for RTs; $F < 1$ for ERs, or with stimulus structure. Mean RTs for compatible, incompatible, and one-stimulus display were 313, 366, and 353 ms, respectively, for the large/global letters, and 404, 496, and 508 ms for the small/local letters. The respective means for percentage errors were 1%, 5.1%, and 2.5% for the large/global letters and 2%, 20%, and 12% for the small/local letters. Duncan's pairwise comparisons showed that performance was faster and more accurate with compatible stimuli than with incompatible and one-stimulus presentations. Incompatible stimuli produced higher error rates than did compatible and one-stimulus presentations. These effects were larger for the detection of small/local letters than for the large/global letters, as indicated by the interaction between compatibility and stimulus size.

Discussion

The results of Experiment 2 replicated the main finding of Experiment 1: subjects' performance was affected by the interaction of attention conditions with task requirements but did not differ between binocular and dichoptic viewing conditions. The three-way interaction among attention condition, tasks, and viewings obtained in Experiment 1 was not replicated.

The present results indicate that the relative size of the stimulus, rather than the level it constituted in a compound stimulus, affected performance. The pattern of results observed in Experiment 1 for global and local letters was replicated in Experiment 2 for larger letters (either single or constituting the global level of a compound letter) and smaller letters (either single or constituting the local level of a compound letter).

Two other effects were replicated. First, subjects' ability to focus attention on the relevant stimulus was as good under dichoptic viewing conditions as under binocular conditions. The results indicate some processing of the stimulus in the unattended eye or field, but probably not to semantic level because the compatibility/incompatibility of the irrelevant information had no effect on performance. This finding is more compatible with early-selection models of attention (e.g., Kahneman, 1973) than with late-selection models (e.g., Deutch and Deutch, 1963). Second, performance under the divided attention condition was also the same under both viewing conditions. Redundant information facilitated performance, and conflicting information reduced accuracy, mainly for the detection of small/local targets.

The identical effects of interaction between attention conditions and tasks under binocular and dichoptic viewing conditions, which was observed in Experiments 1 and 2, suggest that attention allocation depends on the relevant field of stimulation, regardless of whether the entire field is viewed by both eyes or separate fields are presented to separate eyes. Although we interpreted the present findings in terms of attentional factors, the results do not rule out an interpretation in terms of visual acuity (attributable to retinal location). Possibly both attentional and acuity factors underlie the present findings. Experiment 3 was designed to examine the generalization of these findings with a different task in which the relevant stimulus array could not be viewed foveally.

EXPERIMENT 3

Experiment 3 employed a relative-proximity judgment task. Subjects were briefly presented with two pairs of geometrical shapes and had to decide in which pair the shapes were closer to each other. The aim of this experiment was to examine subjects' performance on this task in focused and divided attention conditions under binocular and dichoptic viewing conditions. Whereas the tasks used in the previous experiments involved the processing of aspects of a single object, the present task involved the processing of relationships between objects.

Method

Subjects. Eight male 20- to 28-year-old students with normal vision were paid for participation in the experiment. The same subjects were tested under both dichoptic and binocular viewing conditions. None had participated in the previous experiments.

Stimuli. Four possible pairs of geometrical shapes were used: a pair of squares, a pair of triangles, a pair of circles, and a pair of T-shaped forms. A stimulus array consisted of two pairs of shapes in which each pair was positioned on a different diagonal of an imaginary square that subtended 10.08 deg of visual angle (see Figure 7). The two stimulus arrays were adjacent to each other. Each shape subtended 0.89 deg of visual angle. The distance between the two members of a pair was either short (subtended 3.17 deg of visual angle), medium (subtended 6.34 deg), or long (subtended 9.46 deg). The two relevant pairs of shapes—those for which relative-proximity judgments had to be made—were the pair of squares and the pair of triangles. The combinations of distances defined three types of relative-proximity judgments: *short-long* (in which the distance between the shapes was short in one pair and long in the other), *short-medium* (in which one pair had a short distance and the other had a medium distance), and *medium-long* (in which one pair had a medium distance and the other had a long distance).

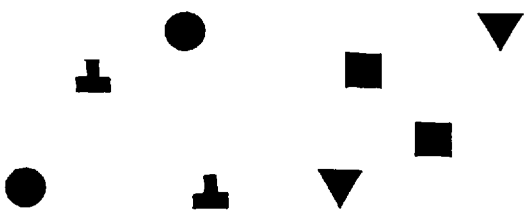

Figure 7. *An example of the stimulus arrays used in Experiment 3.*

Design. The experiment employed a completely within-subject three-factor design: viewing (binocular, dichoptic), types of judgment (short-long, short-medium, long-medium), and attention conditions (focused, divided).

The focused attention condition included 600 trials in 12 blocks of 50 trials each. The first 2 blocks were practice blocks. Also, the first two trials of the 10 experimental blocks were warm-up trials, which were not included in the analysis. The irrelevant stimulus array was either completely identical to the relevant one (i.e., it had the same shapes with the distance relations arranged on the same diagonals), contained the same shapes but in different combinations of distances and diagonals, contained different shapes with the same combinations of distances and diagonals, was completely different (i.e., it had different shapes and different combinations of distances and diagonals), or contained no stimuli.

The divided attention condition included 336 experimental trials, preceded by 100 practice trials. In this condition, two types of trials occurred randomly. In one type, one of the stimulus arrays (presented to one eye or field) contained the two relevant pairs of shapes. Subjects were to detect the relevant array and to make their relative-proximity judgment. There were 192 trials of this kind: in 144 the other stimulus array (presented to the other eye or field) contained two pairs of irrelevant shapes, and in 48 no information was presented to the other eye or field. In the second type of trial that occurred randomly, one of the two relevant pairs was in one stimulus array (presented to one eye or field) and the other relevant pair was in the other stimulus array (presented to the other eye or field). Subjects had to integrate information from both stimulus arrays in order to make the relative-proximity judgment. There were 144 trials of this kind: in 96 the two relevant pairs were on opposite diagonals in the two stimulus arrays, and in 48 they were on the same diagonal across the two arrays.

Procedure. All subjects were tested in the two attention conditions under dichoptic and binocular viewing conditions in four separate experimental sessions, each of which lasted about an hour. The order of the viewing situations, as well as the order of the attention conditions under each viewing condition, were counterbalanced across subjects. Subjects were instructed as to the nature of the stimulus arrays and were asked to judge in which pair of shapes—the squares or the triangles—the shapes were closer to each other. Upon reaching their decision they were to press the corresponding key. The position of each stimulus array on each monitor was determined as follows: an array of four dots indicating the stimulus array was displayed on each monitor, and the stimulus arrays were positioned so that viewing the two arrays of four dots each dichoptically gave rise to a perception of an array of six dots (i.e., two adjacent squares). Note that in the present dichoptic viewing condition, parts of the different stimulus arrays were presented to corresponding loci in the two eyes. In all other respects the present procedure and the apparatus were the same as those of the previous experiments.

Results

Blinking was detected in 0.5% of the trials. Responses on these trials were eliminated from the analyses. Mean RTs and ERs of the relative-proximity judgments for the three types of judgments in the two attention conditions under the two viewing conditions are presented in Figure 8. A three-factor repeated-measures ANOVA (Viewing × Attention × Type of Judgment) indicated significant main effects of attention conditions and types of judgments (all *ps* < 0.01 for both RTs and ERs). There was no main effect of viewing and no significant interactions involving this factor ($F < 1$ for both RTs and ERs). Under the two attention conditions, subjects' responses were the slowest and least accurate when they compared medium with long distances and the fastest and most accurate when they compared short with long distances. The more difficult the relative-proximity judgment, the more it was affected by the demand to divide attention, as indicated by the interaction between attention conditions and types of judgments, $F(2,14) = 6.15$, $p < 0.015$ for RTs; $F(2,14) = 7.27$, $p < 0.007$ for ERs.

In order to compare subjects' performance on integration and no-integration trials in the divided attention condition under the two viewing conditions, a two-factor repeated-measures ANOVA (Viewing × Type of Trial) was performed. The analysis indicated a significant difference between the two types of trials in ERs. $F(1,7) = 6.06$, $p < 0.05$, but not in RTs, $F(1,7) = 1.39$, $p > 0.29$. There was no effect of viewing and no interaction between viewing and types of trials ($F < 1$). The means for percentage error for the integration and no-integration trials were 22% and 14%, respectively. Thus under both viewings, accuracy rate was higher when one of the stimulus arrays contained all the information required for the judgment than when information from the two stimulus arrays had to be integrated in order to perform the judgment.

Discussion

The results of Experiment 3 replicated the main findings of Experiments 1 and 2: subjects' performance was the same under dichoptic and binocular viewing conditions and was affected by the interaction of attention conditions with task requirements. This

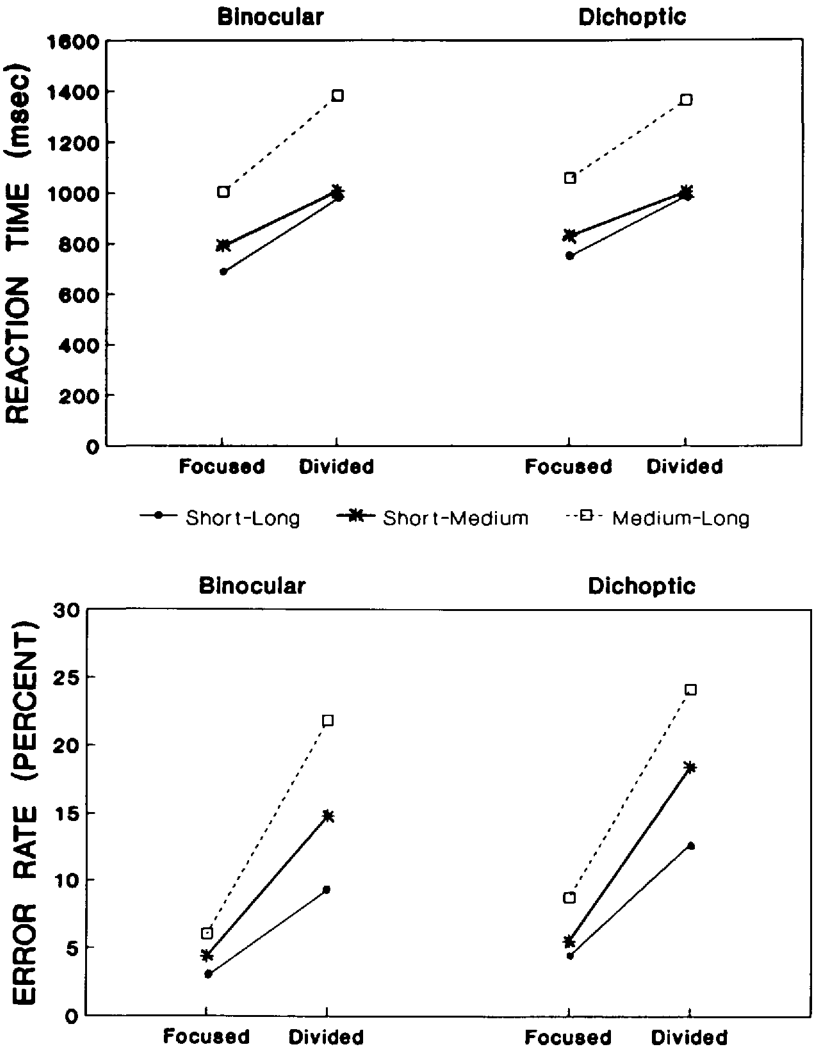

Figure 8. *Mean reaction times and error rates for each type of judgment as a function of attention and viewing conditions in Experiment 3.*

finding is particularly interesting in light of the fact that unlike the dichoptic viewing condition employed in Experiments 1 and 2, in which only one eye was stimulated at any given location, in Experiment 3 parts of the stimulus arrays presented to separate eyes stimulated corresponding loci in the two eyes. Also, the present experiment employed a completely within-subject design, whereas in Experiments 1 and 2 different groups of subjects were tested under the two viewing conditions. However, in both cases viewing did not seem to affect performance.

Given the proximity relations between the judged pairs, the medium-long and the short-medium comparisons were expected to be more difficult than the short-long comparison because the former two required finer discrimination than did the latter. The results show that, indeed, the comparison of short with long distance was easier than the medium-with-long comparison; however, it was not significantly easier than the short-with-medium comparison. This finding may be attributable to the smaller spatial distances involved in the short-medium comparison, which allowed attention to be allocated to a smaller region and thereby increased the capacity for fine discrimination, as suggested by models of visual attention (e.g., Eriksen and St. James, 1986). Note that visual acuity attributable to foveal viewing cannot account for this finding because the relevant array for the short-medium judgment (although involving smaller spatial distances) extended over an area larger than that which could be covered by the fovea.

Response times were longer and error rates were higher under the divided attention condition than under the focused attention condition for all judgments, with a greater effect noted for the medium-long judgment than for the two other judgments. This finding suggests that for judgments involving relatively large spatial distances, the more dependent the judgment was on finer discrimination, the more it was affected by the requirement to monitor two stimulus arrays. This finding is in accordance with the findings of Experiments 1 and 2, in which detection of the small/local letter, which depends on higher resolution, was affected by dividing attention, whereas detection of the large/global letter, which is less dependent on high resolution, was not.

In the divided attention condition, performance was more accurate when one of the stimulus arrays contained the information required for the judgment than when information from the two stimulus arrays had to be integrated, presumably because the former allowed a switch from a divided to a focused attention mode once the relevant stimulus array was detected, whereas the latter required the subject to maintain a divided attention mode in order to perform the judgment.

GENERAL DISCUSSION

The present results suggest that despite the fact that dichoptic viewing is unnatural, it does not necessarily impair subjects' ability to cope with attentional instructions and task requirements relative to that with normal binocular viewing, at least for tasks and exposure durations similar to the ones employed in the present experiments.

Subjects were equally able to focus their attention on one stimulus while ignoring another when the relevant stimulus was presented to one eye and the irrelevant stimulus was presented to the other eye (dichoptic viewing) and when the relevant stimulus was presented to both eyes (binocular viewing). Under both viewing conditions, the irrelevant stimulus was not completely ignored, but its effect was very small. Furthermore, the finding that the nature of the irrelevant information (i.e., whether it was compatible or incompatible with the relevant information) had no effect on performance suggests that it was not processed to the semantic level.

It has often been found that binocular performance is superior to monocular performance, both when threshold and suprathreshold sensitivities are examined, and the advantage is attributed to some mechanism of binocular summation (see Arditi, 1986). The present results, however, indicate no differences between binocular and monocular viewing: when focusing on one briefly presented stimulus and searching for a large/global or a small/local target (Experiments 1 and 2) or performing a relative-proximity judgment (Experiment 3), one eye seemed to do as well as two eyes. It is possible that these findings are attributable mainly to the specific tasks employed (note that most previous work used simple psychophysical tasks). It is also possible, however, that a deliberate allocation of attention overrides a possible advantage of binocular versus monocular viewing. Such a finding has implications for the use of single-eye displays.

Subjects' ability to monitor two stimuli viewed by the two eyes (binocular viewing) was also the same as their ability to monitor two stimuli, each viewed by a separate eye (dichoptic viewing). Under both viewing conditions, compatibility between the two stimuli facilitated performance, whereas incompatibility increased error rates, mainly for the small/local detection (Experiments 1 and 2).

Subjects did not show any differences in their ability to cope with the tasks employed in the present experiments under dichoptic and binocular viewing conditions. Their performance was affected by the requirement to monitor one stimulus or two simultaneously presented stimuli, in a pattern predicted by theories of visual attention. The results of Experiments 1 and 2 do not rule out the possibility that acuity, attributable to retinal location, can account for the effect of attention conditions. However, the results of Experiment 3—in which none of the relevant stimulus arrays could be viewed foveally, even in the focused attention condition—render visual acuity per se less plausible as the only possible account of the results.

Theories of visual attention (e.g., Eriksen and Yeh, 1985; LaBerge, 1983) suggest a trade-off between the size of the visual field over which attention is distributed and its resolution. For example, Eriksen and Yeh (1985) suggested that visual attention has the characteristics of a zoom lens: when the lens's power increases, the size of the effective visual field decreases and the capacity for fine discrimination increases (e.g., Eriksen and St. James, 1986). Similarly, according to the attentional spotlight metaphor, processing capacity and processing speed decrease as the size of the attentional spotlight increases (LaBerge, 1983). Hence these theories predict a decrease in discrimination of details when attention is distributed over the entire field compared with when it is focused on a smaller region. Indeed the results of the present experiments are compatible with this prediction: monitoring two stimuli (which presumably is a condition of distributed attention) impaired performance (relative to focusing attention on one stimulus) on tasks that were more dependent on fine resolution. Thus monitoring two stimuli did not cause any difficulty for the detection of large/global targets, whereas it did increase reaction times and error rates for detection of small/local targets (Experiments 1 and 2). Similarly, the medium-long proximity judgment was most affected by the requirement to monitor two stimulus arrays (Experiment 3). The mechanism that mediates monitoring two simultaneously presented stimuli seems to be different from the mechanism involved in monitoring two levels of a compound stimulus (see discussion of Experiment 1).

It is perhaps not surprising that allocation of attention was found to be independent of the way information was presented to the eyes; after all, attention is a central mechanism, and as such it is not expected to be affected by peripheral manipulations. For example, it is a well-established finding that attention can be independent of eye fixation (e.g., Posner, Snyder, and Davidson, 1980). Yet it was also demonstrated that when attention is directed away from the center of the fovea, it becomes less efficient the farther away that it moves (e.g., Egly and Homa, 1984). This suggests that attention can be affected by certain peripheral manipulations. However, in the present experiments, the way information was presented to the eyes (binocularly or dichoptically) did not seem to have any effect on allocation of attention.

It is important to realize, however, that the finding that allocation of attention and task performance were independent of viewing may be due, at least in part, to the specific viewing manipulations employed—which minimized the probability for the onset of binocular rivalry under dichoptic viewing conditions—and to the discrete nature of the tasks used. The exposure duration of the stimuli in the present experiments was short (150 ms). It has been reported that the onset of binocular rivalry in dichoptic presentation takes between 200 and 400 ms (Anderson, Bechtoldt, and Dunlap, 1978; Arditi, 1986; Wolfe, 1982). Thus it is possible that the short exposure did not allow binocular rivalry to arise even in Experiment 3 (where some binocular rivalry could have arisen because of partial stimulation of corresponding loci in the two eyes), consequently yielding no differences in performance between dichoptic and binocular viewing conditions. We obtained some preliminary results that show an effect of viewing with a continuous tracking task (Gopher, Grunwald, Straucher, and Kimchi, 1990).

To conclude, the present findings suggest that with discrete tasks, under a viewing situation in which binocular rivalry is not very likely to arise (namely, when only one eye is stimulated at any given location, as in Experiments 1 and 2), and/or when exposure duration is relatively short (as in Experiments 1, 2, and 3), subjects' ability to allocate attention and perform task requirements when each eye is presented with a separate stimulus is the same as when the entire field of stimulation is viewed by both eyes. Further research is needed in order to examine the effect of attentional instructions and its interaction with task requirements in dichoptic versus binocular viewing in conditions in which a strong competition between the eyes may arise because of binocular rivalry, and with a wider range of tasks. These issues are currently under investigation in our laboratory.

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