Journal of Experimental Psychology:
Human Perception and Performance
1992, Vol. 18, No. 3, 837-848

0096-1523/92/$3.00

Splitting Focal Attention

Umberto Castiello
Istituto di Fisiologia Umana, Università di Parma
Parma, Italy

Carlo Umiltà
Dipartimento di Psicologia Generale, Università di Padova
Padua, Italy

The study was based on the inverse relationship between the effect of attention on reaction time (RT) and the size of the area over which focal attention is allocated. Independent occurrence of this in 2 locations in the opposite hemifields would be evidence of attention splitting. In Experiment 1, in which the 2 locations were denoted by empty boxes, there was an inverse relationship between size of the stimulated box and RT. Experiment 2 replicated the finding with different stimulation conditions. In Experiment 3, no relationship was found between RT and length of a cuing line. In Experiment 4, in which attention was manipulated by central cues, there was an effect of box size on valid and neutral trials but not invalid trials. Observers could split focal attention and manipulate simultaneously 2 independent attentional foci on objects located in the opposite hemifields.

According to a well-known metaphor of James (1890/1950), the focus of attention is likened to the beam of a spotlight. This spotlight possesses a specific size, moves from one location to another in analog fashion rather than jumping instantaneously, and enhances the efficiency of processing in the regions that lie within its beam (e.g., see Posner, 1980; Umiltà, 1988). A variation of this metaphor was proposed by Eriksen and his colleagues (Eriksen & St. James, 1986; Eriksen & Yeh, 1985), who maintained that the focus of attention should instead be likened to a zoom, or variable-power, lens. The zoom lens can cover a variable portion of the visual space, and resolution improves when this region is constricted.

The evidence available so far does not allow the separation of the spotlight and the zoom-lens accounts of focal attention. Several studies have shown that the spatial extent of focal attention is not fixed but can vary according to task demands (e.g., Castiello & Umiltà, 1990; Egeth, 1977; Eriksen & St. James, 1986; Henderson, 1991; LaBerge, 1983; LaBerge & Brown, 1986). This is explicitly predicted by the zoom-lens hypothesis, but it does not create difficulties for the spotlight hypothesis either. It has also been shown that there is an inverse relationship between size of the attentional focus and processing efficiency within its borders (Castiello & Umiltà, 1990; Egeth, 1977; Eriksen & St. James, 1986; Henderson, 1991). This is no doubt in favor of the zoom-lens hypothesis, of which such inverse relationship is a necessary consequence. The spotlight hypothesis can easily accommodate it as well, however.

The two hypotheses might be contrasted by considering how focal attention is shifted in space. As said, according to the spotlight account, focal attention shifts from one location to another in analog fashion by following a continuous trajectory. On the other hand, according to the zoom-lens account, there is a narrowing of the attentional focus on the target location. Although some studies have obtained results that at first sight seem to be in agreement with the notion of analog attention movements, the issue is far from being settled (e.g., see discussions in Rizzolatti, Riggio, Dascola, & Umiltà, 1987; Umiltà, Riggio, Dascola, & Rizzolatti, 1991).

The important point here is that both positions maintain that focal attention cannot be split and can only be assigned to adjacent regions of the visual field (in particular, see Posner, 1980; Posner, Synder, & Davidson, 1980). Interestingly enough, this view is not shared by the gradient model of spatial attention (e.g., see Downing & Pinker, 1985; LaBerge & Brown, 1989). For example, LaBerge and Brown (1989) explicitly state that the attentional gradient could form two modes or peaks corresponding to the locations of two targets. Considering that focal attention is represented in their model by the peak of an attentional gradient at a given location, this is clearly at variance with the idea that focal attention operates at only one location at a time.

The notion of a unitary attentional focus is apparently supported by a number of studies that have shown that benefits in processing efficiency are confined to locations adjacent to the position where focal attention was directed, whereas no benefits (and very often costs) are observed in nonadjacent locations (e.g., see Eriksen & St. James, 1986; Eriksen & Yeh, 1985; Posner, 1980; Posner et al., 1980). Yet there are some results that could be construed as showing that focal attention can be split. For example, M. L. Shaw and P. Shaw (1977) showed that the identifiability of a briefly exposed letter was enhanced when it appeared at either of two highly probable locations. M. L. Shaw (1978) found that speed of response to targets shown in different locations depended on the probability associated with the various locations. It is possible, however, that these results were caused by attention switching rather than attention splitting. In other words, the observers could have attended sometimes to one location and sometimes to the other location across trials, but not to both simultaneously.

This research was supported by Consiglio Nazionale delle Ricerche Contract 9100259-PF41 and a grant from the Ministero della Università e della Recerca Scientifica e Tecnologica to Carlo Umiltà.

We thank V. DiLollo for suggesting Experiment 2b and two anonymous reviewers for suggesting Experiment 4.

Correspondence concerning this article should be addressed to Carlo Umiltà, Dipartimento di Psicologia Generale, Università di Padova, piazza Capitaniato, 3, 35139 Padua, Italy.

In addition, Müller and Findlay (1987) explicitly claimed that spatial attention can be divided between different locations. They used a display in which targets could appear at one of four locations on an imaginary square. When two locations were cued, these locations were both in the left or right field, both in the upper or lower field, or both along the diagonal of the square. In other words, subjects were never required to attend to regions separated by noncued regions. Therefore, the fact that attentional benefits could be found at both locations can be explained by assuming that subjects spread attention to adjacent regions. Although the condition in which the two locations lay on the diagonal is intriguing, these results are not incompatible with the notion that the attentional focus cannot be split.

Another intriguing finding for the notion of a unitary focus of attention is that of Egly and Homa (1984). In their experiments, the subjects' task was to maintain fixation at the center and to identify or localize a displaced letter shown at one of eight locations on one of three rings surrounding the fixation point. Contrary to the prediction of the unitariness of the attentional focus, it appeared that attention could be concentrated and restricted along the cued ring at the expense of locations that lay either outside or inside it. It thus seemed that observers were capable of allocating attention in rather complex and nonunitary configurations. These results, however, were not confirmed by Juola, Crouch, and Cocklin (1987).

Evidence in favor of the fact that attention might sometimes be assigned to noncontiguous regions of the visual field comes from studies that have suggested that attention is directed to perceptual groups. Duncan (1984) examined attention to objects superimposed at the same location and found that two attributes of one such object could be reported more accurately than two attributes from different objects. Although Duncan's results do not demonstrate that attention can be assigned to noncontiguous regions of the visual field, they do demonstrate—at odds with either the spotlight or the zoom-lens metaphor—that observers can select one of two superimposed forms that provide no obvious spatial basis for selection.

More damaging for the notion of the unitariness of the attentional focus are the results of a study by Driver and Baylis (1989). By using common motion to produce perceptual grouping, they showed that distant distractor letters that moved with a target letter yielded more interference than static distractors that were closer to the target. It thus appears that focal attention is assigned to perceptual groups rather than to contiguous regions of the visual field.

Driver and Baylis (1989) interpreted the fact that attention can be focused on perceptual groups whose components are spatially dispersed as evidence against the spotlight metaphor, as well as against the zoom-lens model or the gradient model, which they considered to be "subtle variations on the spotlight theme" (p. 448).

The possibility that the attentional focus is not unitary arose also from the results of a previous study in which we (Castiello & Umiltà, 1990) found evidence that observers were able to control the width of the attentional focus in two regions of the visual field that were not contiguous. These experiments will be presented in some detail because they help understand the rationale of the experiments reported here.

Basically, Castiello and Umiltà (1990) adopted Posner's (1980) paradigm, which exploits the covert orienting of attention, and in which differences in reaction time (RT) to stimuli at expected and unexpected locations are used as a measure of the efficiency of detection attributable to the orienting of attention. There were two well-circumscribed locations, clearly marked by empty boxes, where the imperative stimulus could be presented. They lay in opposite hemifields, 20° apart. On some trials, both locations were precued, and the imperative stimulus was equally likely to occur in either location (*neutral trials*). On other trials, only one location was precued, and the probability was much higher that the stimulus would have occurred in that location (*valid trials*) than in the other (*invalid trials*).

For present purposes, the important point is that the boxes that marked the possible locations of the imperative stimulus could have different sizes. This feature allowed to test whether there was an inverse relationship between width of the attentional focus and processing efficiency. The results confirmed the prediction by demonstrating that on valid trials, provided that the interval between the cue and the imperative stimulus was long enough, RT increased as a direct function of box size. The RT for invalid trials was slower than for valid trials and did not show any relationship with box size. In addition, the RT for neutral trials was slower than that for valid trials, but surprisingly enough, it did show the inverse relationship with box size.

The interpretation of the results obtained on valid trials is rather straightforward. The spatial extent of the attentional focus can be adapted to the size of the area in which the imperative stimulus will appear, and efficiency of processing decreases when the extent of the attentional focus increases. If one extends this interpretation to the results obtained on neutral trials, then the outcome becomes problematic for any model that maintains that focal attention can only be directed to contiguous regions of the visual field. In fact, it appears that observers were able to produce simultaneously two attentional foci located in opposite hemifields and to vary their sizes in accordance with task demands.

The aim of the following experiments was to corroborate further the notion that focal attention can be split, by showing that observers can produce two attentional foci that operate simultaneously and independently in the opposite visual hemifields.

Experiment 1

The experimental situation was very similar to that used in Experiment 1a of Castiello and Umiltà (1990), which in turn was a variation of Posner's (1980) paradigm. There were two empty boxes located in the opposite hemifields, and the task was to respond after stimulus detection (i.e., simple RT), regardless of the box where the stimulus occurred. Trials were only of the neutral type in the sense that the stimulus was always equally likely to occur in either box.

The crucial feature of the experiment was that the two boxes differed in size. That is, the box on the left was always larger or smaller than that on the right. The intention was to see whether the inverse relationship between box size and speed of response still held true. We reasoned that this would have been strong evidence in favor of the notion of two separate attentional foci operating simultaneously and independently in the two visual hemifields.

Method

Subjects. Eight students (4 women and 4 men) from the University of Parma (Parma, Italy) participated in the experiment and were paid for their collaboration. They were all right-handed according to the Edinburgh Inventory (Oldfield, 1971), reported normal or corrected-to-normal vision, and were ignorant as to the purpose of the experiment. They each attended for two sessions in consecutive days.

Apparatus and materials. The subject sat in front of a video screen driven by an IBM PC 286. The head was positioned in an adjustable head-and-chin rest so that the distance between the eyes and the screen was approximately 50 cm. The visual display (see Figure 1) comprised a black fixation cross (0.5° × 0.5°), two empty black square boxes of variable size (1.1°, 2.2°, and 3.3°), and the imperative stimulus (a red dot with a diameter of 0.4° and a luminance of about 36 cd/m²).

The fixation cross was shown at the center of the screen, the two boxes were shown 10° (center to center) to the left or right of it, and the imperative stimulus was always shown at the geometrical center of one of the boxes, which were never the same size. Note that as shown by Castiello and Umiltà (1990, Experiment 2), the actual position of the stimulus is immaterial, provided that it lies within the box.

The response to the imperative stimulus was emitted by pressing a key on the computer keyboard (*B*) with the right index finger. Eye position was monitored through a closed-circuit TV camera and displayed on a screen, on which markers showed the fixation point and two points 1° to the left and right of it. Trials on which an eye movement in excess of 1° was detected were discarded and replaced at the end of the corresponding block (see the following).

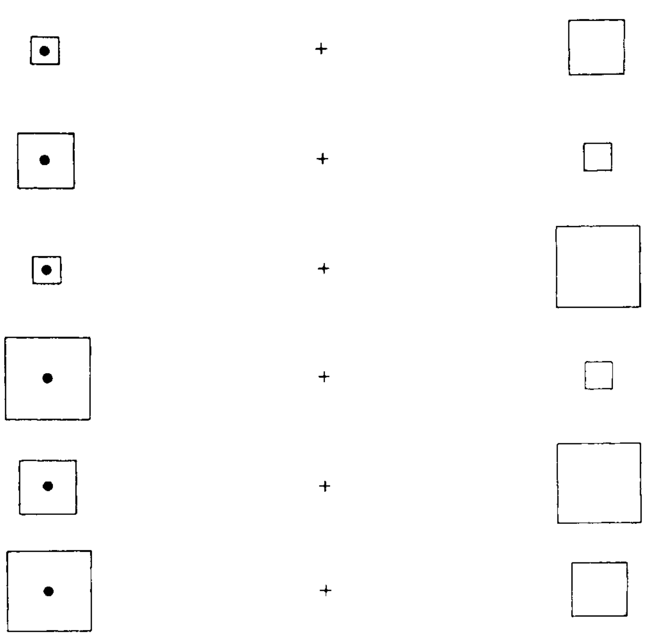

Figure 1. Schematic representation of the displays used in Experiment 1. (Note that the dot [i.e., the imperative stimulus] was red.)

Procedure. On each trial, the sequence of events was as follows. The fixation cross was shown and remained on until the end of the trial. Then, after a 500-ms interval, the boxes were shown and also remained on until the end of the trial. Finally, after a further interval of 50 or 500 ms, the imperative stimulus appeared for 100 ms within one of the boxes. In 20% of the trials (catch trials), no imperative stimulus was presented.

The instructions were to fixate the center cross while trying to split attention between the boxes and to press the designated key as fast as possible in response to the imperative stimulus. The RT was measured from stimulus onset to response emission. The subject was also instructed to refrain from responding to catch trials. Trials for which RT was less than 150 ms or in excess of 1,000 ms were considered errors and were replaced at the end of the block.

Subjects were individually tested in two experimental sessions, subdivided in four blocks separated by 5-min rests. A block was composed of about 450 trials, half with an interval between the boxes and the imperative stimulus of 50 ms and half with an interval of 500 ms. The two intervals were randomly intermixed. All combinations of box size were presented randomly in each block. Before the beginning of the first experimental session, the subject performed in a practice session of 200 trials.

Results and Discussion

Errors, including eye movements, were rare (less than 1%) and were not analyzed. Correct RTs (See Table 1) were entered into a three-way repeated measures analysis of variance, in which the variables were hemifield (left of right), interval (50 or 500 ms), and box size (1.1°, 2.2°, 3.3°).

The main effects of interval and box were significant, $F(1, 7) = 148.42$, $p < .001$, and $F(2, 14) = 16.61$, $p < .001$, respectively. The RT was faster with the longer interval than with the shorter interval (246 vs. 338 ms) and was inversely related to the size of the box (283 ms for the smallest box, 288 ms for the intermediate box, and 304 ms for the largest box). Pairwise comparisons with the Newman-Keuls method showed that the 3.3° box produced RTs slower than either the 1.1° or the 2.2° box.

Only one interaction was significant, namely the one between interval and box, $F(2, 14) = 10.65$, $p < .01$. It showed that the effect of box size was present with the longer interval (226, 245, and 264 ms; all differences were significant at $p < .05$ or less) but absent with the shorter interval (338, 331, and 343 ms).

The interval main effect most likely occurs because the boxes acted as warning signals, and response preparation was better after 500 than 50 ms. More interesting for the purposes of the experiment was the interaction, which qualified the main effect of box. It appears that as already demonstrated by Castiello and Umiltà (1990), the inverse relationship between box size and speed of response emerges only when there is enough time for the attentional focus to be enlarged or narrowed, depending on the nature of the cue (see the *Results and Discussion* section of Experiment 4 for possible explanations).

Assuming that this effect occurs because the width of the attentional focus can be controlled and made to fit the size of

Table 1
Reaction Times (RTs, in Milliseconds) for Experiments 1–4 as a Function of Cue-Stimulus Interval and Cue Size

	Experiment 1				Experiment 2a		Experiment 2b		Experiment 3	
	50-ms interval		500-ms interval		600-ms interval		500-ms interval		500-ms interval	
Cue size	RT	*SD*	RT	*SD*	RT	*SD*	RT	*SD*	RT	*SD*
1.1°	338	28	226	15	230	11	264	17	254	14
2.2°	331	22	245	12	246	10	282	16	251	12
3.3°	343	18	264	16	263	15	305	21	248	18

a designated area, the obvious conclusion seems to be that in this experiment the observer produced and controlled two attentional foci. Because this conclusion counters the widely accepted notion of the unitariness of the attentional focus (see the introduction), we deemed it necessary to confirm these results in a second experiment.

Note that the results of Experiment 1 do not easily lend themselves to an interpretation in terms of a unitary attentional focus that spans the distance between the two boxes. (Note also that this point was made in the introduction when we discussed the study of Müller & Findlay, 1987.) This interpretation was clearly tenable in the case of the neutral trials of our previous study (Castiello & Umiltà, 1990), in which box size was completely confounded with the extent of a putative unitary focus that included both boxes. Although here this area did not covary with box size, such an alternative account, though unlikely, could still be entertained because displays that contained larger boxes tended to be wider overall. More precisely, the two displays with a 1.1° box are on average narrower than the two displays with a 2.2° box, which in turn are narrower on average than the two displays that contain a 3.3° box (see Figure 1).

To verify the interpretation that attention is focused on the display as a whole rather than split, we conducted an additional analysis of variance on RTs obtained with the longer interval, with display size (narrow, intermediate, or large) as the only within-subjects variable. If we number the displays from top to bottom in Figure 1, the narrow displays were Displays 1 and 2, the intermediate ones were Displays 3 and 4, the large ones were Displays 5 and 6. Although RT did vary as predicted, the differences were small and nonsignificant (239, 245, and 251 ms, for the narrow, intermediate, and large displays, respectively).

There can be little doubt, however, that the alternative interpretation that would be more damaging for our hypothesis is in terms of attention shifting across trials. On each trial, subjects could have attended to only one box. In this way, half of the trials would have become valid and the other half invalid. If this had happened, one should predict the presence of two peaks in the RT distributions, namely one peak for valid trials and one peak for invalid trials. Inspection of the six RT distributions yielded by the combinations of hemifield and box size when the interval was 500 ms (see Figure 2) showed very little evidence of bimodality, however.

Experiments 2a and 2b

In Experiment 1 the boxes were intended to act as cues indicating which portions of the visual field could contain the imperative stimulus. It is known (e.g., see Humphreys & Bruce, 1989), however, that between nonoverlapping stimuli, paracontrast—which is equivalent to forward masking between overlapping stimuli—may occur. It is therefore possible that the stimulus dot suffered more lateral (paracontrast-type) masking from the flanking borders of the box. It is not clear, however, why the masking effect should have become weaker when the flanking bars got closer to the stimulus (i.e., when the box was smaller) for the 500-ms interval only. At any rate, in Experiment 2 the conditions were altered to render an interpretation in terms of "peripheral" effects less likely. In addition, in this experiment we aimed to test the generality of the findings of Experiment 1 by using different stimulation conditions.

Experiment 2a

Method

Subjects. Eight students were paid for participating in the experiment. They were selected as before and were ignorant of the purpose of the experiment. None had taken part in Experiment 1.

Apparatus and materials. These were the same as in Experiment 1 except that pale-blue solid squares were used in place of the empty boxes.

Procedure. The sequence of the events was as follows. The fixation cross signaled the beginning of a trial and was present throughout it. After a 500-ms interval, the two squares were shown for 500 ms. An interval of 100 ms elapsed after the disappearance of the squares, and then the imperative stimulus was presented. Note that the interval between the onset of the squares and the presentation of the imperative stimulus was always 600 ms and that the squares had already disappeared when the imperative stimulus was delivered. In all other respects, the procedure was identical to that already described for Experiment 1.

Results

The very few errors observed (less than 1%, including eye movements) were not analyzed. Correct RTs (see Table 1) were entered into a two-way repeated measures analysis of

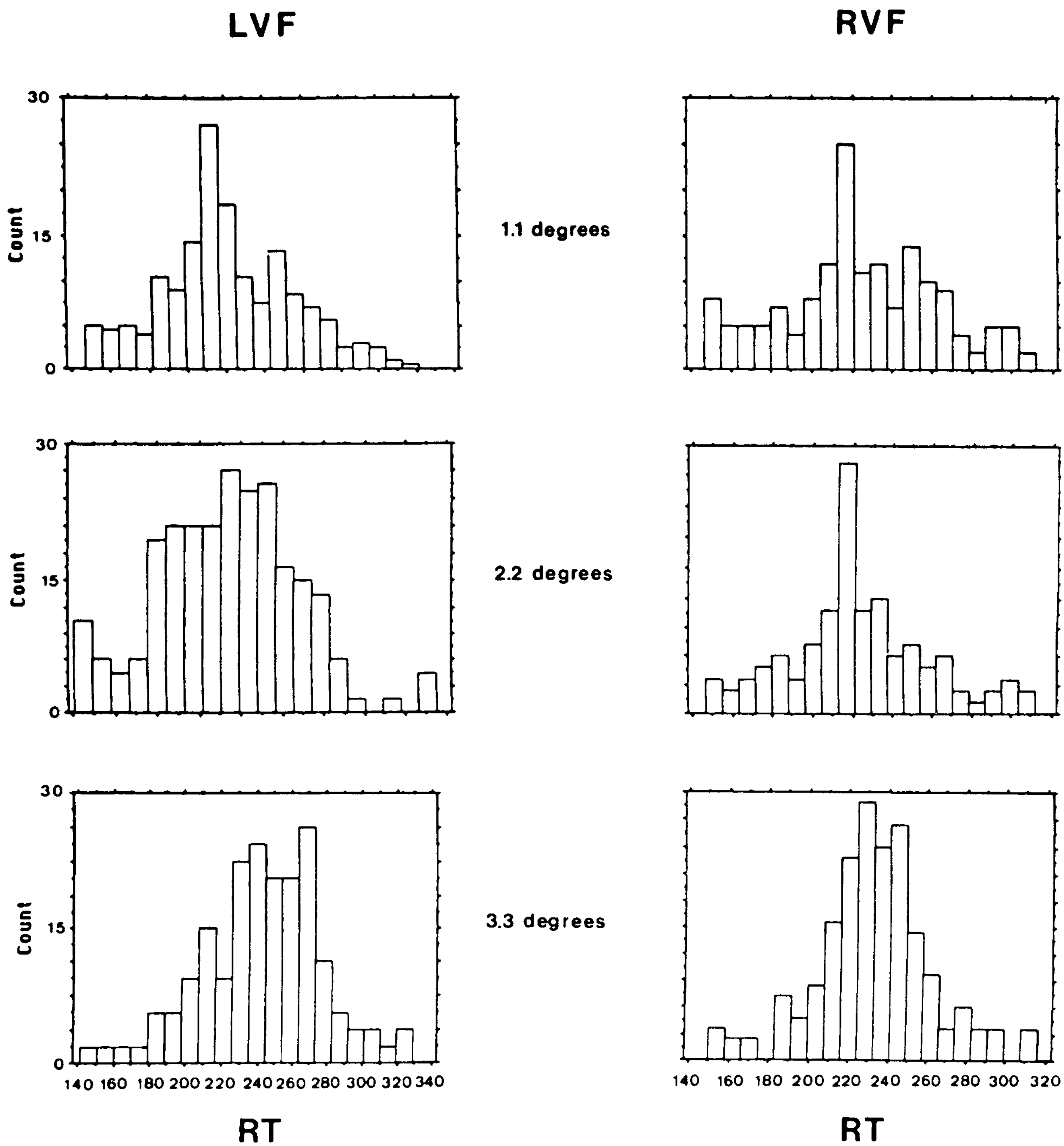

Figure 2. Experiment 1: The six reaction time (RT) distributions yielded by the combinations of hemifield and box size. (The RTs are in milliseconds. RVF denotes right visual field, and LVF denotes left visual field.)

variance with hemifield (left or right) and square size (1.1°, 2.2°, or 3.3°) as variables.

The only significant source of variance was the main effect of square, $F(2, 14) = 21.61$, $p < .001$. Pairwise comparisons ($ps < .05$ or less) showed that RT varied inversely as a function of the size of the square: 231 ms for a 1.1° square, 246 ms for a 2.2° square, and 263 ms for a 3.3° square.

As in Experiment 1, we conducted an analysis of variance to ascertain whether RT depended on the size of the display as a whole. In this case, the main effect of display was not significant, and the differences were rather small. Nevertheless, they were in the predicted direction: 240 ms for the narrowest displays, 248 ms for the intermediate displays, and 251 ms for the largest displays.

Inspection of the six RT distributions yielded by the combinations of hemifield and size indicated that none was a mixture of two underlying distributions (see Figure 3).

Experiment 2b

Method

Subjects. Eight students were selected as before and were paid for participating in the experiment. None was aware of the purpose of the experiment or had taken part in the previous experiments.

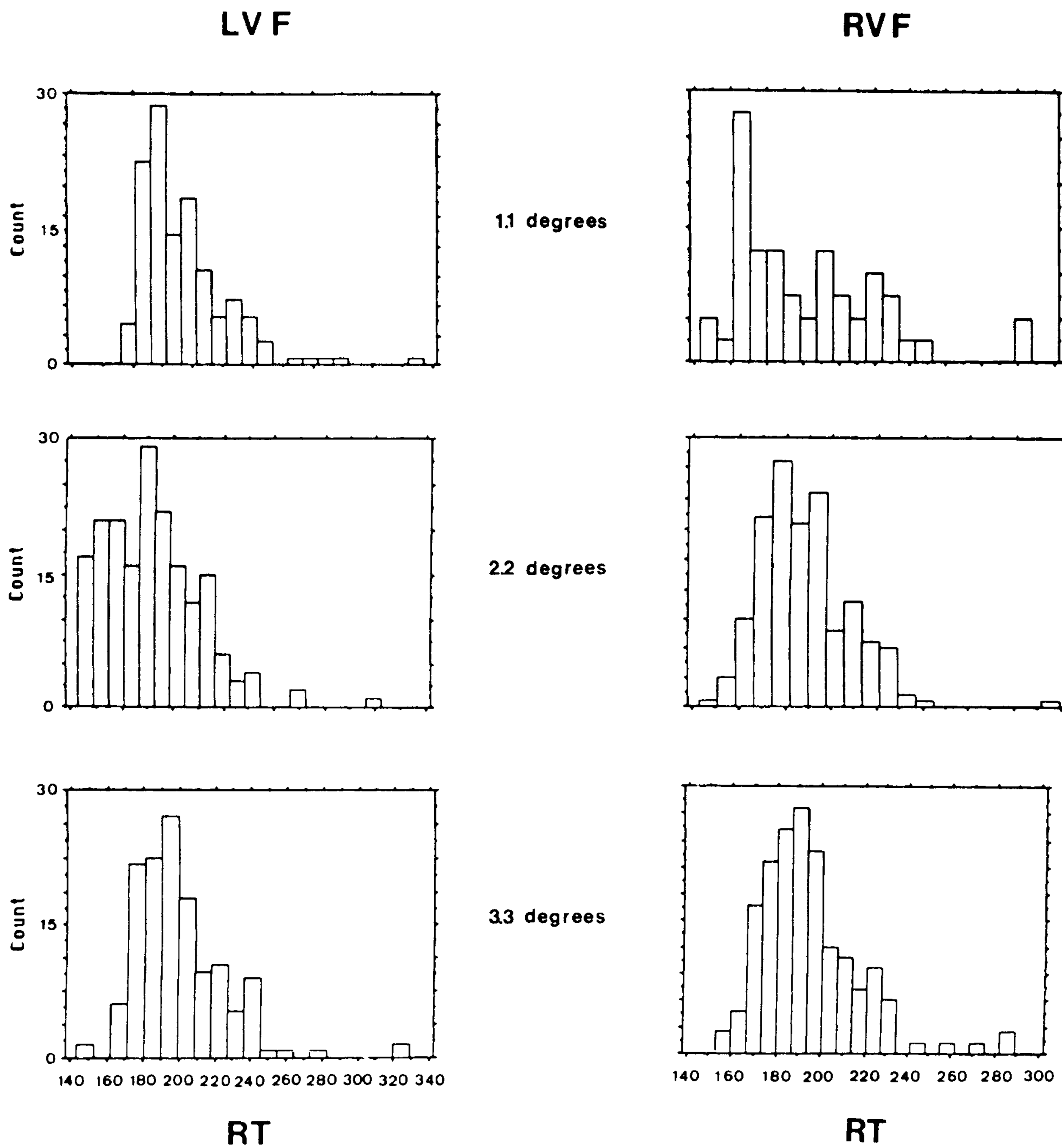

Figure 3. Experiment 2a: The six reaction time (RT) distributions yielded by the combinations of hemifield and square size. (The RTs are in milliseconds. RVF denotes right visual field, and LVF denotes left visual field.)

Apparatus and materials. These were the same as in Experiment 1, but the boxes were not actually shown. They were instead replaced by eight dots (0.5° in diameter) located at the corners of two imaginary squares.

Procedure. It replicated exactly that of Experiment 1 except that the interval between the onset of the dots and the presentation of the imperative stimulus was always 500 ms.

Results and Discussion

The errors, including eye movements, were about 1% and were not analyzed. Correct RTs (see Table 1) were entered into a two-way repeated measures analysis of variance, with the same variables as in Experiment 2a.

The main effect of square was significant, $F(2, 14) = 25.64$, $p < .001$. Pairwise comparisons ($ps < .05$ or less) showed that RT was inversely related to size of the cue: 264 for the smallest square, 282 ms for the intermediate square, and 305 ms for the largest square. In addition, the main effect of hemifield was significant, $F(1, 7) = 11.84$, $p < .01$, which indicates that RT was faster in the right hemifield than in the left hemifield (278 vs. 290 ms).

We performed a second analysis of variance on RTs of Experiments 1 (only the 500-ms interval) and 2 (2a and 2b separately). It had one between-subjects variable, the type of cue, and two within-subjects variables, hemifield and size of the cue.

The only significant sources of variance were size and cue, $F(2, 42) = 98.72$, $ps < .001$, and $F(2, 21) = 6.72$, $ps < .01$, respectively. The first confirmed that RT depended on size of the cue, being 240 ms for the 1.1° cue, 257 ms for the 2.2° cue, and 278 ms for the 3.3° cue. The second showed that responses for the dots (284 ms) were slower than those for either the boxes or the squares (246 ms in both cases).

The analysis of variance conducted on the data of Experiment 2b with display size as the only within-subjects variable showed that the differences were small and not significant, even though once again and somewhat disturbingly, RT was fastest for the narrowest displays (276 ms), intermediate for the intermediate displays (283 ms), and slowest for the largest displays (292 ms).

Inspection of the six RT distributions did not provide any evidence of bimodality (see Figure 4).

The results of Experiment 2 were no doubt in full agreement with those of Experiment 1 in showing that observers can use the information provided by the cue to adapt the width of the attentional focus independently, albeit simultaneously, in the two hemifields. We then conducted a third experiment to elucidate which features of the cues had allowed the subjects to manipulate their attentional foci.

Experiment 3

In the two previous experiments, as well as in the study of Castiello and Umiltà (1990), the cues indicated circumscribed areas of the visual fields. It therefore seems that subjects were required to focus attention on objects in the visual fields rather than on "empty" spatial locations. (Note also that the dots conveyed the subjective impression of forming perceptual objects). One wonders whether the same results can be obtained when the task consists of focusing attention on much less clearly defined portions of the visual fields, which do not constitute perceptual objects. In other words, the question is whether the width of the attentional foci can be manipulated when their targets do not present themselves as perceptual objects.

Method

Subjects. Eight students, who had not taken part in the previous experiments, were selected as before and were paid for participating in the experiment.

Apparatus and materials. These were the same as in Experiment 1 except that only the upper sides of the boxes were used.

Procedure. This was the same as in Experiment 1 except that only the 500-ms interval was used. Of course, the boxes were now replaced by horizontal lines corresponding to their upper sides. The subjects were told to try to split attention between the areas roughly defined as below the two lines.

Results and Discussion

As usual, errors, including eye movements, were very rare (less than 1%) and were not analyzed. Correct RTs (see Table 1) were submitted to a two-way repeated measures analysis of variance, with hemifield (left or right) and line length (1.1°, 2.2°, or 3.3°) as variables.

No source of variance attained statistical significance. In particular, the main effect of line did not even approach it, $F(2, 14) = 0.74$, $p = .5$. Apparently, RT was not affected by the length of the cuing line: 254 ms for 1.1°, 251 ms for 2.2°, and 248 ms for 3.3°.The results were very clear in showing that in the absence of perceptual objects on which to anchor attention, observers were unable to manipulate their attentional foci successfully. The indication of an empty spatial location does not seem to be sufficient for allowing a good fit between the width of the attentional focus and the extent of the area in which the imperative stimulus is about to be presented.

Experiment 4

So far, the reasoning has been in terms of attention splitting over space rather than over time. We have assumed that subjects were able to control independently the width of two separated attentional foci located in the two hemifields. As said, however, this is not the only possible interpretation. The results of Experiments 1 and 2 may have originated from a mixture of valid and invalid trials. Valid trials would have occurred when the subject happened to have directed attention to the location where the imperative stimulus was then presented. Invalid trials would have occurred when the subject happened to have directed attention to the location opposite that of the imperative stimulus. Of course, this would have constituted splitting attention over time, not over space.

This alternative interpretation was addressed by inspection of the RT distributions, which provided very little evidence of bimodality. Yet whether a mixture of valid and invalid

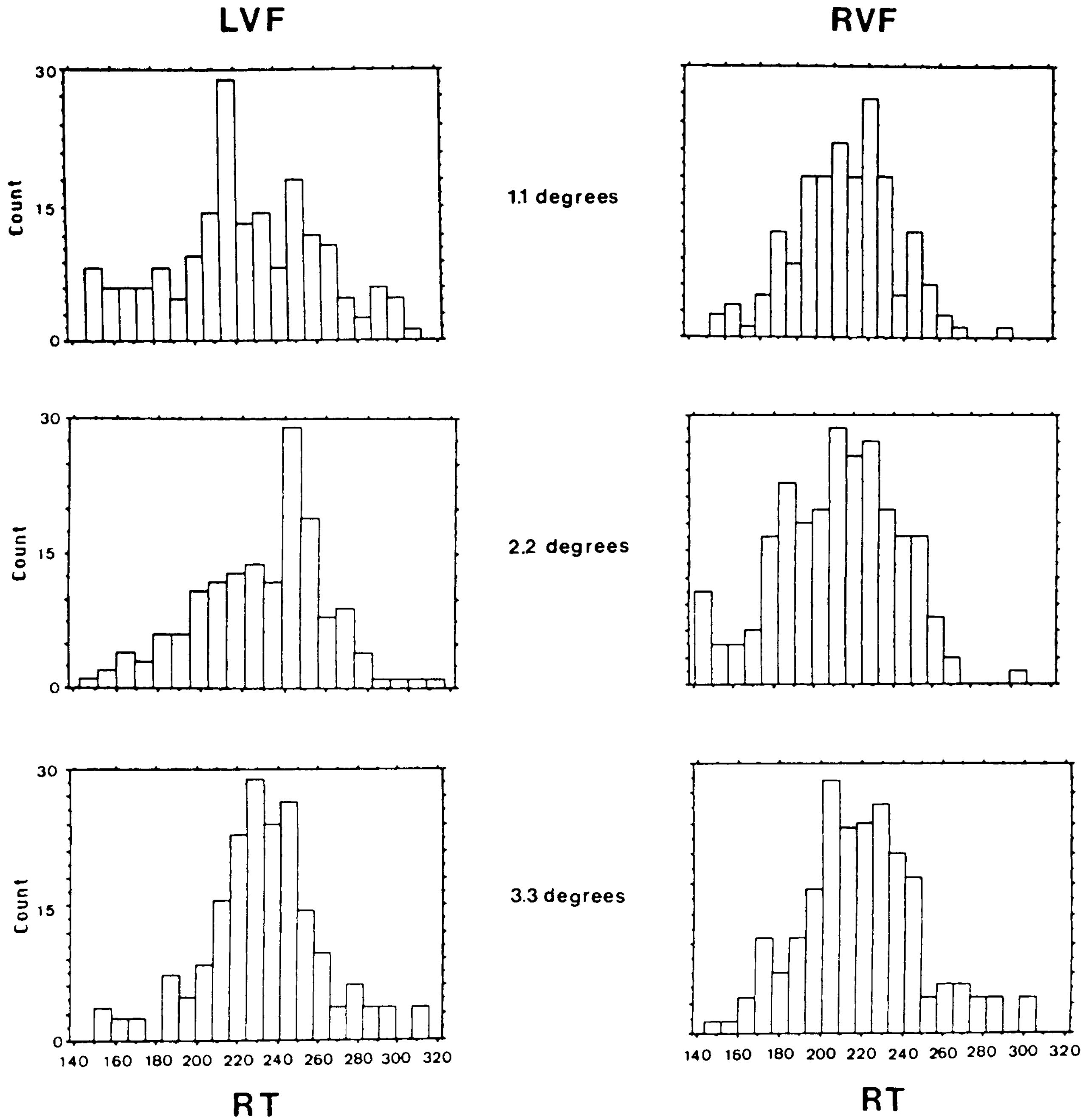

Figure 4. Experiment 2b: The six reaction time (RT) distributions yielded by the combinations of hemifield and square (4 dots) size. (The RTs are in milliseconds. RVF denotes right visual field, and LVF denotes left visual field.)

trials can yield a distribution whose bimodality is discernible is highly problematic. A mixture of valid and invalid trials could instead be detected by a test for homogeneity of variance in an experiment in which valid and invalid trials were explicitly included as well. The idea is that if on neutral trials attention is actually split between the two cued locations, then the variance observed for a mixture of RTs to valid and invalid trials should be greater than the variance observed for RTs to neutral trials only. In contrast, the variances observed for RTs to "pure" neutral and valid trials should not differ. We conducted Experiment 4 to test these predictions.

Experiment 4 had the secondary aim of generalizing the findings of the previous experiments to a condition in which attention was oriented voluntarily. The distinction between automatic and voluntary orienting, originally introduced by James (1890/1950), was developed by Posner (1980), Jonides

(1981), and more recently by Müller and Rabbitt (1989; also see Henderson, 1991; Jonides & Yantis, 1988; Umiltà et al., 1991; Yantis & Jonides, 1984). These studies showed that observers can be induced to shift attention through the use of two types of visual cue. Peripheral cues, abrupt discontinuities in the visual field, have reflexive control over attention deployment. When peripheral cues are presented, a shift of attention is automatically elicited. Observers also have internal control over spatial attention, so when they are directed by a centrally positioned cue they can voluntarily shift attention.

Considering that two independent mechanisms have been proposed for automatic and voluntary shifts of attention and that in the previous experiments we had used only peripheral cues, it seemed interesting to ascertain whether similar results could be obtained with central cues. Note, however, that the automatic-voluntary distinction applies only to the way attention is shifted, not to the way the width of the attentional focus is manipulated. In fact, it seems very likely that the effects of the size of a cue shown at the periphery are always exogeneously produced (see Henderson, 1991).

Method

Subjects. Eight subjects, who had not been previously tested and were ignorant of the purpose of the experiment, were selected as before.

Apparatus and materials. These were essentially the same as in Experiment 1 except that the cue was shown just above the fixation mark. The cue could be a cross (1.5° × 1.5°), a leftward pointing arrow (2° in length), or a rightward pointing arrow (2° in length).

Procedure. The most relevant alteration in the procedure was that there were valid, invalid, and neutral trials.

Subjects were run in two sessions about a day apart. In each session there were four blocks separated by 5-min rest intervals; each block consisted of about 400 trials. In each block, 10% of the time the cue was not followed by the imperative stimulus (catch trials). Of the remaining trials, 75% had a directional arrow cue, whereas 25% had a nondirectional cross cue (neutral trials). Of the trials with a directional cue, 67% were preceded by an arrow pointing toward the box in which the imperative stimulus was to be presented (valid trials), whereas 33% were preceded by an arrow pointing toward the box opposite the one in which the imperative stimulus was to be presented (invalid trials).

The subject was instructed to direct attention to the cued box in the case of a directional cue and to split attention between the two boxes in the case of a nondirectional cue.

On each trial, the timing of the events was as follows. The fixation mark was presented and followed by the boxes (500-ms interval) and the cue (1,000-ms interval). The fixation mark, the boxes, and the cue remained on until the end of the trial. After a further interval of 500 ms since the appearance of the cue, the imperative stimulus was shown within one of the boxes for 100 ms.

Results and Discussion

Errors, including eye movements, were rare (about 1.5%) and were not analyzed. Correct RTs (see Table 2) were submitted to a three-way repeated measures analysis of variance with hemifield (left or right), box size (1.1°, 2.2°, or 3.3°), and type of trial (valid, neutral, or invalid) as variables.

Table 2
Reaction Times (RTs, in Milliseconds) for Experiment 4 as a Function of Cue Validity and Cue Size

	Valid trials		Neutral trials		Invalid trials	
Cue size	RT	*SD*	RT	*SD*	RT	*SD*
1.1°	216	20	239	20	298	12
2.2°	234	15	259	21	300	18
3.3°	252	19	277	17	301	16

The main effects of box and trial were significant, $F(2, 14) = 302.90$, $p < .001$, and $F(2, 14) = 163.83$, $p < .001$, respectively. They indicated that RT was inversely related to box size (251 ms for the smallest box, 264 ms for the intermediate box, and 277 ms for the largest box) and depended on the type of trial (234 ms for valid trials, 258 ms for neutral trials, and 300 ms for invalid trials).

Of greater importance was the significant interaction between box and trial, $F(4, 28) = 88.18$, $p < .001$. As confirmed by subsequent pairwise comparisons ($ps < .05$ or less), RT varied inversely with box size for valid and neutral trials but not for invalid trials (see Table 2).

The two main effects were to be expected. The fact that RT depended on type of trial confirmed that observers are able to direct attention in accordance with central cues (e.g., see Posner, 1980; Rizzolatti et al., 1987; Umiltà et al., 1991). The fact that RT depended on the size of the box confirmed the results of Experiments 1 and 2.

The interaction was much more interesting. As proposed by Castiello and Umiltà (1990), it can be interpreted by assuming that the size of the box affected speed of response only when the subject was given enough time to manipulate the span of the attentional focus. This happens on valid and neutral trials, provided that the interval between the cue and the imperative stimulus is long (see Experiment 1). On invalid trials, the subject fitted the attentional focus to the size of the "wrong" box. After stimulus presentation, attention has to be reoriented quickly to the other side, and there is not enough time for manipulating the focus. A second and perhaps more convincing possibility is that on invalid trials (or on neutral trials if the interval is very brief; see Experiment 1), when the subject switches attention toward the stimulated box, the imperative stimulus is already there. The stimulus thus provides a salient target object for attention, which overrides the effect of the box. Note that this interpretation is in accordance with the view that size effects are exogeneously driven.

At any rate, whichever explanation is given for the lack of size effects on invalid trials, the important point is that speed of response varied inversely as a function of box size on neutral trials. This corroborates the results of the previous experiments and supports the notion that two attentional foci can be manipulated independently in the two visual fields.

The absence of the size effect at the invalid location rules out two alternative explanations that do not require the focus of attention to be split. The first is that the attentional focus is always fitted to the size of only one box *after* stimulus presentation. If this operation occurred after stimulus presentation, one would expect a size effect on invalid trials as well because on invalid trials the attentional focus can be directed to the just-stimulated box and made to fit its size. The second alternative explanation, which was already taken into consideration in planning Experiment 2, is that the effect of box size is caused by peripheral factors that somehow render the imperative stimulus more salient when shown within smaller boxes. This explanation cannot be invoked here because stimulation conditions were identical for valid, neutral, and invalid trials.

Yet there is still the possibility that attention was split over time, not over space. We addressed this issue by performing two tests of the homogeneity of variance for each subject. The first was the ratio of the variance of valid and invalid trials to the variance of neutral trials; the second was the ratio of the variance of neutral trials to the variance of valid trials. For the first test, the F statistic was significant ($ps < .05$ or less) for 7 of 8 subjects. For the second test, the F statistic was not significant (all $Fs < 1.12$) for 7 of 8 subjects.

The F tests indicated that valid and invalid trials together formed a mixed distribution, whereas neutral trials did not originate from a similar mixture of valid and invalid trials. It can therefore be concluded that on neutral trials subjects did not use the strategy of splitting attention over time by focusing on one location only.

General Discussion

Two influential models that were proposed to characterize the features of focal attention, namely the spotlight model (e.g., Posner, 1980) and the zoom-lens model (e.g., Eriksen & St. James, 1986), share the view that focal attention can only be assigned to contiguous regions of the visual field. In addition, the position according to which focal attention is directed to objects, as defined by perceptual grouping principles, rather than to regions of space (e.g., Driver & Baylis, 1989; Duncan, 1984), does not dispute the unitariness of the attentional focus. This rival account does suggest that focal attention may sometimes be assigned to noncontiguous regions of the visual field, but that happens when these noncontiguous regions are unified into a single object by some Gestalt grouping factors.

All of this is surprising because the notion of a unitary attentional focus does not seem to be demanded by the features of the models. There is no theoretical reason for maintaining that there is only one single spotlight or one single zoom lens instead of two (or maybe more than two). Similarly, focal attention might be directed to two perceptual objects instead of just one.

Apparently, the notion of a unitary attentional focus was based on empirical rather than theoretical grounds. In particular, support for this notion came from those studies that showed that the effects of attention were limited to locations adjacent to where focal attention had been directed (e.g., Eriksen & St. James, 1986; Eriksen & Yeh, 1985; Posner, 1980). Those studies (of which there are far fewer), which seemed to show that attention could be directed simultaneously to nonadjacent areas of the visual field (Egly & Homa, 1984; Müller & Findlay, 1987; M. L. Shaw, 1978; M. L. Shaw & P. Shaw, 1977), either lend themselves to alternate interpretations or proved difficult to replicate.

The results of the present study are important because they provide solid empirical evidence against the notion of a unitary attentional focus. As said before, LaBerge and Brown (1989) have explicitly stated within the framework of their gradient model of spatial attention that the attentional gradient can be double-peaked. The present findings, however, cannot be taken as supportive of the gradient model against either the spotlight or the zoom-lens model. In fact, the unitariness of the attentional focus is demanded by neither of the latter models.

The fact that the attentional focus can be split gives rise to further interesting questions. For example, one can ask whether processing resources are also split between the two attentional foci, with processing efficiency thus diminished with respect to when there is only a single attentional focus. On the basis of the results of Experiment 4 and of Castiello and Umiltà (1990), in which RT for neutral trials (on which focal attention is split) proved to be slower than RT for valid trials (on which the attentional focus is unitary), one may argue that processing within a single focus is more efficient than processing within a split focus. An alternative possibility is that the slower RT for neutral trials than for valid trials is not due to a single supply of resources being divided up between two foci but rather to the fact that producing and maintaining two foci is more resource-demanding.

A second question concerns whether the attentional focus can be split only between locations that lie in opposite hemifields or whether there can be two attentional foci within the same hemifield. The two independent attentional foci might depend on independent attentional mechanisms located in the two cerebral hemispheres (e.g., see Kinsbourne, 1987; Ladavas, Petronio, & Umiltà 1990).

A third question is whether splitting the attentional focus is limited to two locations or whether observers are able to produce several attentional foci spread across distant positions in the visual field. Results like those reported by Egly and Homa (1984) seem to favor the possibility of having several attentional foci arranged in rather complex configurations.

The present study is relevant also for another issue concerning focal attention. If one conceptualizes focal attention in terms of a spotlight or a zoom lens, it follows that attention can be directed to a particular region of space (see also Miller, 1988). According to another account, focal attention cannot be directed to particular regions of space but rather to the objects that occupy those regions (e.g., Driver & Baylis, 1989; Duncan, 1984). That is, focal attention cannot be "rooted" to particular spatial locations, unless objects render these locations perceptually salient (see also Humphreys & Bruce, 1989; Miller, 1988; Tipper, Brehaut, & Driver, 1990).

The results reported here clearly favor the object-based view of focal attention. In Experiments 1, 2, and 4, in which there were salient perceptual objects to which attention could be directed, subjects were able to manipulate the attentional focus and make it fit the size of the cue. In contrast, manipulating focal attention was not possible in Experiment 3, in which line cues defined locations in the visual field to which focal attention was to be directed. It is true that the lines were perceptual objects, but they lay above the relevant locations. These locations were not themselves occupied by objects. It therefore seems that the presence of objects is a necessary condition for allowing control over the width of the attentional focus. In other words, observers can focus attention on objects but not on empty regions of space.

The fact that objects are necessary for allowing a correct focusing of attention can help explain a current controversy in the literature. Hughes and Zimba (1985, 1987) tried to map the width of the attentional focus but failed because they were unable to show that benefits were spatially restricted around the cued location. Rather, they found that when observers were cued to expect a target at a specific location, uniform benefits were obtained with probes shown at a variety of distances from the cued location within the same visual hemifield (or quadrant), whereas uniform costs were found throughout the contralateral hemifield (or quadrant). In contrast, by using a very similar paradigm, Rizzolatti et al. (1987; see also Henderson, 1991; Umiltà et al., 1991) found benefits at the cued location and increasing costs, both in the same hemifield and in the opposite hemifield, as a function of the distance between the cued location and the probed location. Interestingly enough, the main difference between the studies of Hughes and Zimba (1985, 1987) on one side and those of Rizzolatti et al. (1987) and Umiltà et al. (1991) on the other is that in the former the cued position was signaled by a vertical line, whereas in the latter it was included within boxes identical to those used in the present Experiment 1. It can be argued, therefore, that only in the latter there were objects on which to focus attention. Note that Zimba and Hughes (1987) made a similar proposal in an attempt to reconcile discrepancies between results obtained in an empty visual field and results obtained when luminous markers indicate the exact location of the expected target.

References

Castiello, U., & Umiltà, C. (1990). Size of the attentional focus and efficiency of processing. *Acta Psychologica, 73*, 195–209.

Downing, C. J., & Pinker, S. (1985). The spatial structure of visual attention. In M. I. Posner & O. S. M. Marin (Eds.), *Attention and performance XI* (pp. 171–187). Hillsdale, NJ: Erlbaum.

Driver, J., & Baylis, G. C. (1989). Movement and visual attention: The spotlight metaphor breaks down. *Journal of Experimental Psychology: Human Perception and Performance, 15*, 448–456.

Duncan, J. (1984). Selective attention and the organization of visual information. *Journal of Experimental Psychology: General, 113*, 501–517.

Egeth, H. (1977). Attention and preattention. In G. H. Bower (Ed.), *The psychology of learning and motivation* 11 (pp. 277–320). New York: Academic Press.

Egly, R., & Homa, D. (1984). Sensitization of the visual field. *Journal of Experimental Psychology: Human Perception and Performance, 10*, 778–793.

Eriksen, C. W., & St. James, J. D. (1986). Visual attention within and around the field of focal attention: A zoom lens model. *Perception & Psychophysics, 40*, 225–240.

Eriksen, C. W., & Yeh, Y. Y. (1985). Allocation of attention in the visual field. *Journal of Experimental Psychology: Human Perception and Performance, 11*, 583–598.

Henderson, J. M. (1991). Stimulus discrimination following covert attentional orienting to an exogenous cue. *Journal of Experimental Psychology: Human Perception and Performance, 17*, 91–106.

Hughes, H. C., & Zimba, L. D. (1985). Spatial map of directed visual attention. *Journal of Experimental Psychology: Human Perception and Performance, 11*, 409–430.

Hughes, H. C., & Zimba, L. D. (1987). Natural boundaries of the spatial spread of directed visual attention. *Neuropsychologia, 25*, 5–18.

Humphreys, G. W., & Bruce, V. (1989). *Visual cognition.* Hillsdale, NJ: Erlbaum.

James, W. (1950). *The principles of psychology.* New York: Dover Press. (Original work published 1890)

Jonides, J. (1981). Voluntary versus automatic control over the mind's eye's movement. In J. B. Long & A. D. Baddeley (Eds.) *Attention and performance IX* (pp. 187–203). Hillsdale, NJ: Erlbaum.

Jonides, J., & Yantis, S. (1988). Uniqueness of abrupt visual onset in capturing attention. *Perception & Psychophysics, 43*, 346–354.

Juola, J. F., Crouch, T., & Cocklin, T. (1987). Voluntary control of attention near the fovea. *Acta Psychologica, 63*, 207–217.

Kinsbourne, M. (1987). Mechanisms of unilateral neglect. In M. Jeannerod (Ed.), *Neurophysiological and neuropsychological aspects of spatial neglect* (pp. 69–86). New York: Raven Press.

LaBerge, D. (1983). Spatial extent of attention to letters and words. *Journal of Experimental Psychology: Human Perception and Performance, 9*, 371–379.

LaBerge, D., & Brown, V. (1986). Variations in size of the visual field in which targets are presented: An attentional range effect. *Perception & Psychophysics, 40*, 188–200.

LaBerge, D., & Brown, V. (1989). Theory of attentional operations in shape identification. *Psychological Review, 96*, 101–124.

Ladavas, E., Petronio, A., & Umiltà C. (1990). The deployment of visual attention in the intact field of hemineglect patients. *Cortex, 26*, 307–317.

Miller, J. (1988). Components of the location probability effect in visual search tasks. *Journal of Experimental Psychology: Human Perception and Performance, 14*, 453–471.

Müller, H. J., & Findlay, J. M. (1987). Sensitivity and criterion effects in the spatial cuing of visual attention. *Perception & Psychophysics, 42*, 383–399.

Müller, H. J., & Rabbitt, P. M. A. (1989). Reflexive and voluntary orienting of visual attention: Time course of activation and resistance to interruption. *Journal of Experimental Psychology: Human Perception and Performance, 15*, 315–330.

Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh Inventory. *Neuropsychologia, 9*, 97–113.

Posner, M. I. (1980). Orienting of attention. *Quarterly Journal of experimental Psychology, 32*, 3–25.

Posner, M. I., Synder, C., & Davidson, B. (1980). Attention and the detection of signals. *Journal of Experimental Psychology: General, 109*, 160–174.

Rizzolatti, G., Riggio, L., Dascola, I., & Umiltà, C. (1987). Reorienting attention across the horizontal and vertical meridians: Evidence in favor of a premotor theory of attention. *Neuropsychologia, 25*, 31–40.

Shaw, M. L. (1978). A capacity allocation model for reaction time. *Journal of Experimental Psychology: Human Perception and Performance, 4*, 586–598.

Shaw, M. L., & Shaw, P. (1977). Optimal allocation of resources to spatial locations. *Journal of Experimental Psychology: Human Perception and Performance, 3*, 201–211.

Tipper, S. P., Brehaut, J. C., & Driver, J. (1990). Selection of moving and static objects for the control of spatially directed attention. *Journal of Experimental Psychology: Human Perception and Performance, 16*, 492–504.

Umiltà, C. (1988). Orienting of attention. In F. Boller & J. Grafman (Eds.), *Handbook of neuropsychology, Vol. 1* (pp. 175–193). Amsterdam: Elsevier.

Umiltà, C., Riggio, L., Dascola, I., & Rizzolatti, G. (1991). Differential effects of central and peripheral cues on the reorienting of spatial attention. *European Journal of Cognitive Psychology, 3,* 247–267.

Yantis, S., & Jonides, J. (1984). Abrupt visual onsets and selective attention: Evidence from visual search. *Journal of Experimental Pscyhology: Human Perception and Performance, 10,* 601–621.

Zimba, L. D., & Hughes, H. C. (1987). Distractor–target interactions during directed visual attention. *Spatial Vision, 2,* 117–149.

Received November 1, 1990
Revision received July 18, 1991
Accepted July 31, 1991 ■