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The Phenomenology of Attention

2. Brightness and Contrast

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The effect of attention on perceived brightness and contrast was investigated in eight experiments. Attention was manipulated by engaging observers in an attention-demanding concurrent task (letter detection) or by directing attention to a location with a peripheral cue. In all of the dual-task manipulations, attention reduced the variability of responses. However, attention did not affect the brightness of stimuli, nor did it affect the amount of simultaneous brightness contrast. Results with peripheral location cues were similar; however, the effect of attention in these experiments could be attributed to nonperceptual factors. The metaphorical ‘‘spotlight’’ of attention reduces observers’ uncertainty about the brightness of a stimulus, but it does not ‘‘illuminate’’ in terms of brightness or contrast.

Titchener proclaimed that 19th century experimental psychology ‘‘discovered’’ attention in the sense of ‘‘the explicit formulation of the problem; the recognition of its separate status and fundamental importance; the realization that the doctrine of attention is the nerve of the whole psychological system’’ (1908/1973, p. 173). Although the claim of discovery may have been overstated (Hatfield, 1996), the topic of attention was certainly central to the founders of experimental psychology and sensory psychophysics. At the focus of the study of attention was the question of how attention affected the appearance of objects. In particular, there was considerable debate as to whether attention affects the *intensity* of a sensation.

The most prevalent view was that attention increased the intensity of a sensation. For example, Ebbinghaus commented that ‘‘Ordinarily the ticking of a clock remains unnoticed. But let the person think of the clock, or of time, and the next tick is clearly perceived’’ (1908, p. 90). Wundt thought that attention not only increased the intensity of weak stimuli, but also increased the intensity of strong stimuli. For example, he stated, ‘‘One notices that when a stimulus reaches consciousness during

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a moment of particular inattention (*Unaufmerksamkeit*), and then repeats at the same intensity, such as the unexpected chiming of a clock tower, the second reception of the stimulus is perceived not only to be clearer but also more intense'' (cited in Titchener 1908/1973, p. 213). Many others, including Titchener and Mach, also subscribed to the thesis that attention increases the intensity of a stimulus. Stumpf proposed a more moderate view, suggesting that only weak sensations are intensified by attention (see, e.g., Pillsbury, 1906/1973, p. 4).

Fechner vehemently denied that attention intensified sensations, stating that ``A gray paper appears to us no lighter, the pendulum-beat of a clock no louder, no matter how much we increase the strain of our attention upon them. No one, by doing this, can make the gray paper look white'' (in James 1890, p. 426). William James (1890) asserted that attention ``makes a sense-impression more intense,'' but then proposed a kind of compensatory mechanism, similar to color constancy, that nullified the effect of attention so that ``the intensification which may be brought about by attention seems never to lead us astray'' (p. 426). The opinion that attention weakens the intensity of an object did not have many supporters (Titchener, 1910, p. 280).

In summarizing this debate, Pillsbury (1908) commented that ``there is probably no other phase of the attention problem which excites so much dispute as the relation of attention to the intensity of a mental process'' (p. 2). Surprisingly, little research has addressed this question in the last half of the 20th century. A natural stimulus domain to investigate the effect of attention on stimulus intensity is that of brightness or contrast of achromatic stimuli. Given previous views, one might propose that attention would either increase the absolute brightness of a stimulus or not affect it at all. Alternatively, attention might affect the perceived contrast of a stimulus with the background rather than affect its brightness.

Festinger, Coren, and Rivers (1970; also see Brussell & Festinger, 1973) proposed that the part of the visual field to which an observer pays attention will show brightness contrast, whereas the part of the visual field that the observer does not attend will show assimilation with the background. Thus, attending to an object will increase the contrast of that object with the background. They tested this hypothesis in three experiments. In all of the experiments, the attention manipulation involved exposure duration. For example, in Experiment 2, they compared a 3-s exposure with a 10-s exposure. Observers had to judge the brightness of gray stripes alternated with either black or white stripes. The authors assumed that with a 10-s exposure, observers had time to pay attention to the target stripes, whereas with a 3-s exposure they could not attend to the stimuli. More contrast was observed with a 10-s exposure than with a 3-s exposure. A serious problem with these experiments is that exposure duration might influence many processes besides attention. Furthermore, there is no reason to believe that observers could not attend to the gray stripes within 3 s.

Contrary to the findings of Festinger and his colleagues, Tsal, Shalev, Zakay, and Lubow (1994) found that attention *reduced* brightness contrast. This study is noteworthy because it was the first to investigate the question of intensity using what appeared to be clear manipulations of attention (but also see Newhall, 1923). Attention was manipulated by using a peripheral spatial cue (Posner, 1980) and/or location certainty (Miller, 1988; Shaw & Shaw, 1977). Their results might seem surprising given the plurality of 19th century opinion that attention increases stimulus intensity.

We will examine this study in detail later in this paper. Whatever the problems with this study may be, it should be acknowledged as the first modern attempt to seriously examine the effect of attention on stimulus brightness.

Our starting point in examining this issue was a series of experiments on the effect of attention on the appearance of objects in the domains of color (hue), location, orientation, and spatial frequency content (Prinzmetal, Amiri, Allen & Edwards, in press). These experiments had two noteworthy characteristics. First, observers responded to stimuli that fell along a dimensional continuum by making a response along that continuum. In most previous research on attention, observers made a categorical response (e.g., red, green). In Prinzmetal et al., however, observers were briefly presented with a small colored disk that varied in hue. Observers responded by selecting a location on a color palette that best matched the stimulus color. Thus instead of making a categorical response, such as ‘‘green,’’ observers could indicate the exact shade of green that they perceived.

There are several advantages to the method used by Prinzmetal et al. (in press). First, observers had an opportunity to specify precisely what they perceived, rather than trying to match one of the experimenter’s response categories. For example, in a typical experiment with response categories of red, green, and blue, if the stimulus appears yellowish-green, the observer cannot accurately indicate the stimulus appearance. The second advantage is that the method is more efficient in data collection than are experiments with categorical responses. In the typical categorical experiment, each trial is either correct or incorrect. In the method used by Prinzmetal et al., on each trial, one can measure the magnitude and direction of the observer’s error. Over a series trials, one can examine the central tendency of responses (i.e., mean response), the variability of responses (e.g., variance, average deviation), and the shape of the distribution of responses. All of these may be used to test various theories of attention. Finally, Prinzmetal et al. illustrated that categorizing continuous stimuli into discrete categories can produce spurious results. We will illustrate an example of this problem in Experiment 4.

Another characteristic of the experiments by Prinzmetal et al. was that they took steps to ensure that the stimuli were well above threshold. Their prime interest was the phenomenological effect of attention. It is difficult to talk about the perceived color of an object that has not been perceived. To ensure that the stimuli were well above threshold, in some experiments, observers had to locate the stimuli as being in either the left or the right visual field. Errors in location were generally under 0.5%. Other experiments contained catch trials, that is, trials in which a stimulus was not presented. Errors at discriminating catch trials (false alarms and misses) were very low. Previous investigators have been concerned that effects of attention might reflect the fact that observers were using stimulus information from the wrong location in making their response on some trials (e.g., Luck, Hillyard, Mouloua, & Hawkins, 1996; Shui & Pashler, 1994). Prinzmetal et al. wanted to ensure not only that the observer used information from the appropriate location, but that the stimuli were above threshold. The possible effect of attention on threshold is a different issue that we will discuss later.

In the studies reported by Prinzmetal et al., attention was manipulated in several different ways, all involving the introduction of a second, dual task. The dual task was to indicate whether a briefly presented matrix of letters contained the target letter F or T. The assumption was that it is difficult to attend to two different stimuli, in different locations, at the same time. Some of the experiments compared dual-task performance when the dual-task stimuli appeared at the same time (letters and colored disk) with performance when they appeared one at a time (e.g., Duncan, 1980; Hoffman, 1978, 1979; Prinzmetal & Banks, 1983). Other experiments varied the distance between the dual-task stimuli under the assumption that it is difficult to spread attention to different locations (Hoffman, Nelson, & Houck, 1983). Finally, the difficulty of the letter identification task was varied to gauge its influence on the other task (i.e., color identification). To the extent that the letter task was easy, it did not require much attention, leaving processing resources for the color identification task (e.g., Bonnel, Stein, & Bertucci, 1992; Navon & Gopher, 1979; Sperling & Melchner, 1978). All of these attention manipulations had similar effects.

In each of the stimulus domains investigated by Prinzmetal et al. (color, line orientation, location, spatial frequency content), the main effect of attention was to decrease the variability of observers' responses. They interpreted the decrease of variability with attention in terms of reduction of uncertainty about the stimulus. Consider, for example, the experiments with color (hue). In a trial with attention, an observer might be very certain that the stimulus was a certain shade of green (e.g., chartreuse). However, without attention, the observer might be uncertain about the precise color of the stimulus, only know that it was ''greenish.'' Over trials, this effect of attention would translate into greater variability of responses when attention is diverted.

The effects of attention on the mean response were generally small and varied with stimulus domain. For example, in one location experiment, there was a small bias to locate the stimulus closer to the center of gaze (0.14°). Other investigators have also found this bias in location (e.g., Chastain, 1982, 1986; Wolford, 1975; Wolford & Shum, 1980). In one experiment, this bias was reduced with attention, but the effect of attention in biasing location was not replicated in another experiment.

Likewise, in some of the color experiments, there were small biases or shifts in the mean perceived color for some of the colors that we tested. These biases were reduced with attention; however, the shifts produced by manipulating attention were not consistent across experiments. In the experiments on orientation and spatial frequency, there were large systematic shifts in the mean value, but these shifts did not vary with attention. For example, in the experiment on orientation perception, observers reported lines that were near but not quite vertical as being inclined further from vertical. These biases in orientation perception have been found by other investigators (see Huttenlocher, Hedges, & Duncan, 1991; Schiano & Tversky, 1992, for a review). Attention did not influence the magnitude of these shifts.

The general conclusion that emerged from Prinzmetal et al. (in press) is that attention affects the variability of responses. In conditions with attention, responses had less variance than in conditions without attention. In terms of shifts in the mean response, attention either had no effect or operated to overcome biases in perception. Thus, these results can be considered consistent with those reported by Tsal et al.

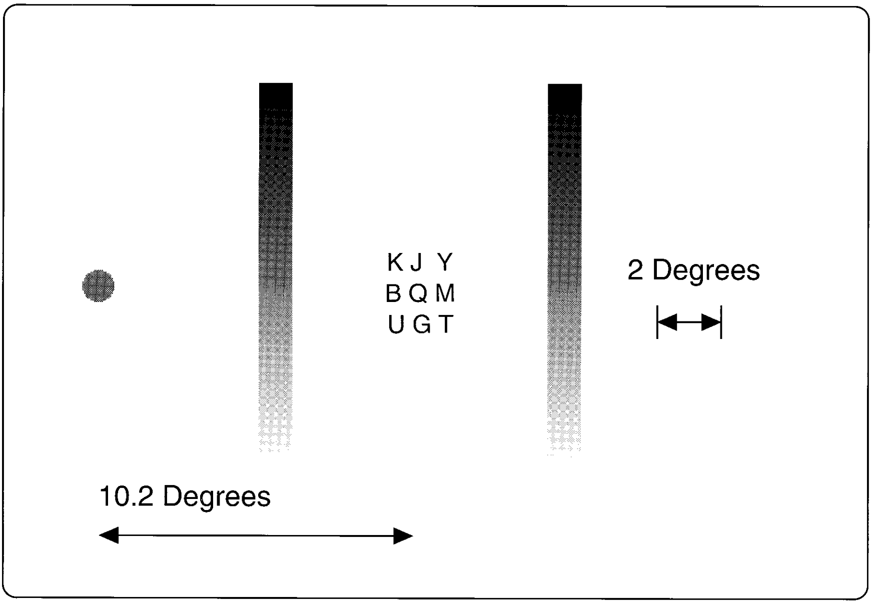

FIG. 1. Sample stimulus from Experiment 1, simultaneous presentation condition.

(1994), who reported that attention decreased simultaneous brightness contrast. However, the procedures employed by Prinzmetal et al. differed from those used by Tsal et al. in several ways, which we will discuss later.

This paper has two parts. In the first, we applied the methods used by Prinzmetal et al. to the question of how attention affects the perceived brightness of a stimulus (Experiments 1 to 3). In these experiments we found that attention decreased the variance of observers' responses, but it did not increase or decrease brightness or contrast. In the second part (Experiments 4 to 8), we attempted to reconcile our results with those reported by Tsal et al.

EXPERIMENT 1

The goal of Experiment 1 was to investigate the effect of attention on the perceived brightness or contrast of an achromatic stimulus using methods that were similar to those used by Prinzmetal et al. (in press). On each trial, observers were briefly presented with two stimuli: an achromatic disk that varied in brightness and a 3 × 3 matrix of letters that contained either the target letter F or T (see Fig. 1). Observers had two main tasks: indicate the brightness of the disk and classify the target letter as an F or a T. To assess whether the briefly presented peripheral disks were above threshold, observers also had to locate the disk as being on the left or right side of the display. There were two attention conditions. In the simultaneous condition, the disk and letters were presented at the same time. In the successive condition, the letters were presented first, followed by the disk. To the extent that it is difficult to attend to two things at the same time, the simultaneous condition ought to be more difficult than the successive condition. On half of the trials, the background of the monitor was white (as shown in Fig. 1) and on half it was black.

Method

Procedure. Two brightness response palettes were present throughout each block of trials (see Fig. 1). A trial began and ended with a fixation dot presented between the palettes. On simultaneous trials, a 3×3 matrix of letters was presented between the response palettes. At the same time, an achromatic disk was presented at one of two randomly selected locations in the periphery for 67 ms. Following termination of the stimulus, a cross-shaped cursor appeared on the screen. Observers were instructed to move the cursor, with a mouse, to the location on the response palette that most closely matched the brightness of the disk.[2] They then pressed the left button on the mouse if the letter matrix contained the letter F and pressed the right button if the matrix contained the letter T. Observers indicated the location of the disk by using the left palette if the stimulus appeared in the left visual field and using the right palette if it appeared in the right visual field. Thus by pressing one button, observers indicated the location of the disk (left or right), the brightness of the disk, and the identity of the target letter. After the observer responded, the cursor disappeared and the fixation dot reappeared. The next trial began after 0.5 s.

Successive trials were similar except that the letter matrix appeared first for 67 ms. Following a blank interval of 0.5 s, the achromatic disk appeared for 67 ms. Thus the exposure duration was the same for both simultaneous and successive trials. On successive trials, since observers did not know in which of the two locations the gray disk would appear, they could not move their eyes prior to the presentation of the disk.

Each block contained 80 trials, with half of the trials using successive presentation and with half using simultaneous presentation. The order of trials within a block was random. The background (white or black) was varied every other block, with half of the observers beginning with the black background. Data were collected over six blocks of trials. The experiment lasted approximately 1 h.

The following feedback was given to observers during a trial. When observers responded with the incorrect letter, the computer emitted a brief tone. If the observer responded with the wrong palette, indicating a location error, the computer emitted a two-tone sequence that sounded like a foghorn. Observers were not given any feedback during a block about their brightness accuracy, but between blocks they were told their average absolute deviation in palette steps from the stimulus to their responses (i.e., response precision). They were not given any information about the direction of their errors (e.g., too bright vs. too dim) because such feedback may have biased observers' responses, artifactually reducing contrast. For example, with the white background, stimuli will appear darker than they are (brightness contrast).

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[2] Arend and Spehar (1993b) argue convincingly that monochromatic variations in a traditional stimulus-surround display, such as that used here, are ambiguous. Observers could treat differences as variations in illuminance or reflectance. Under these conditions, Arend and Spehar (1993b) found that their observers made brightness (or brightness-contrast) matches. Hence, we believe that our observers were also making brightness judgments rather than lightness judgments.

Feedback indicating that responses were too dark could induce observers to respond that the stimuli were brighter than they appeared.

During practice, observers were first shown the stimulus with an exposure duration of 0.5 s. After the observers demonstrated that they understood and could perform the task, the exposure duration was successively lowered, over approximately 30 trials, until it was 67 ms. Observers then had a minimum of one block of 80 trials for practice with the same background (black or white) as during the first block of data collection.

Stimuli. The displays were presented on a 13-in. Apple monitor controlled by a Macintosh II computer.[3] The monitor had a screen resolution of 72 pixels per inch (approximately 28 pixels per centimeter). Observers sat 40 cm from the monitor with their heads restrained by a chin rest. When the background was black, the fixation point and the matrix of letters were white; when the background was white, they were black. The brightness palettes were created by continuously increasing the luminance in 254 steps, with 1 corresponding to the darkest value on the monitor and 254 corresponding to the brightest. Viewing was with normal overhead fluorescent lighting. The resulting luminance for each palette step can be calculated as

$$\mathrm{cd/m^2} = (-.71) + (.415)(N),$$

where N is the palette step number (1 to 254). Measurements were taken with a Minolta Chroma meter (Model CS100), and the above equation accounted for more than 99% of the variance in the relation between N and cd/m^2.

There were eight disk luminance values that corresponded to the following palette step values: 40 (the darkest), 65, 90, 115, 140, 165, 190, 215 (brightest stimulus). These values can be converted to cd/m^2 with the previously given formula. Thus, the stimuli were taken from approximately evenly spaced steps along the response palette. Observers were not told that there were only eight stimulus values, and none appeared to notice this constraint on the stimuli. Each stimulus luminance was used an equal number of times in a block of trials. Figure 1 is drawn to scale, with dimensions in degrees of visual angle indicated.

The letters in the 3×3 matrix were created with Helvetica 12-point type. The target letter (F or T) and target position within the matrix were randomly chosen on each trial. The eight nontarget letters were randomly chosen from the remaining letters in the alphabet.

Observers. Twelve observers participated in this experiment and in each of the experiments reported in this paper, except where indicated. No observer participated in more than one experiment. They were recruited from the Psychology Department subject pool at the University of California, Berkeley. In this experiment, observers' ages ranged from 17 to 26 years. Observers were given course credit for their participation. Across all of the experiments reported in this paper, approximately half of

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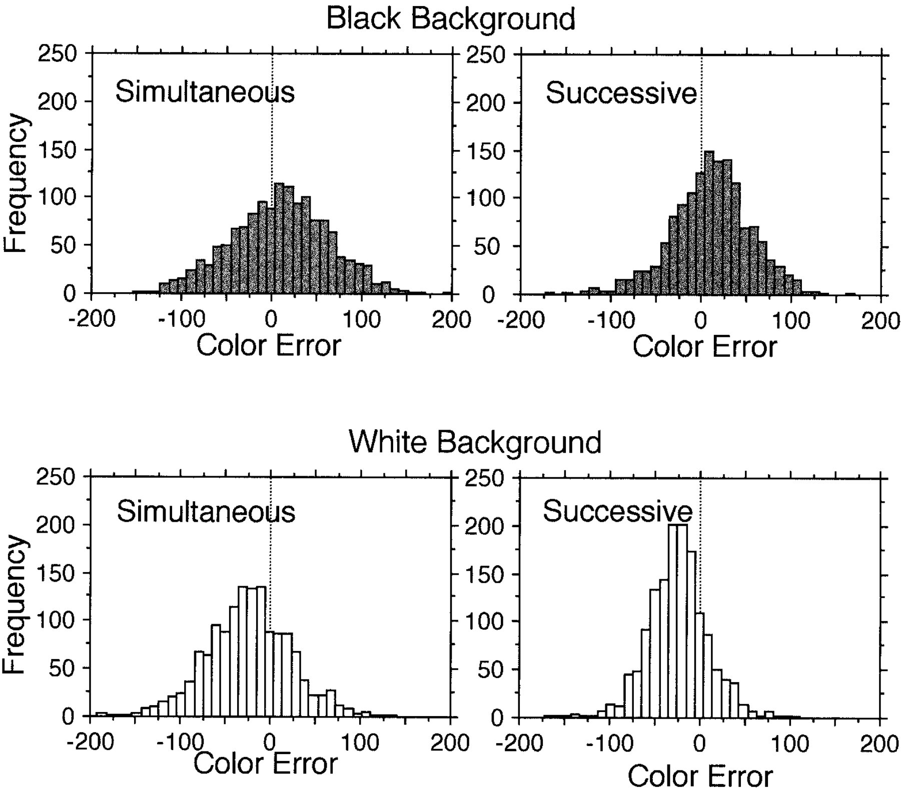
[3] The computer programs that were used in this research can be obtained from the authors. They require a two- or four-button programmable mouse, such as a Kensington Thinking Mouse. To receive the programs, please send a 3.5-in. disk and a self-addressed stamped envelope to the authors.


Black Background

White Background

FIG. 2. Distribution of errors from Experiment 1.

the observers were male and half were female. All of the observers reported having normal or corrected-to-normal vision.

Results

We assumed that if observers could correctly locate the stimuli, the stimuli were above threshold. It is clear that the briefly presented disks were well above threshold since the observers mislocated the disks on less than 0.18% of trials.

To analyze the effect of attention on the brightness and contrast, we first calculated an error score for each trial. The error score was the difference between the response palette index and the stimulus palette index. A positive error score indicated that the observer reported the stimulus as being brighter than it was, and a negative error score indicated that the observer reported the stimulus as being darker than it actually was. The distribution of error scores for the four attention/background conditions is shown in Fig. 2 (including all responses of all observers). The results could be described fairly well by a normal distribution. Note that there appears to be a shift in the mean response depending on the background so that on the black background the stimuli appear brighter and on the white background they appear darker. Also, there is greater variability with simultaneous presentation than with successive presentation. To test for these trends, we conducted ANOVAs on the variability of the error scores and the means of the distributions shown in Fig. 2.

For a measure of variability, we calculated the average absolute deviation of each error score from the mean for each attention/background condition. This calculation was done separately for each observer. The average absolute deviation is the mean of the absolute value of the deviations from the mean of each condition.[4] The average absolute deviation is preferred as a measure of dispersion because it is more robust to violations of assumptions of analysis of variance than the standard deviation (Keppel, 1991, p. 102).

Attention had a marked effect on the variability of brightness responses. The average deviation of each score from the mean was 37.7 and 28.8 palette steps, for simultaneous and successive presentation, respectively, $F(1, 11) = 72.43$, $p < .01$. Each of the 12 observers had less dispersion of responses around the mean response with successive presentation. We will argue later that the reduction in response variability with attention should be thought of as a reduction in uncertainty.

The average absolute deviation was also greater on the black background than on the white background. The average absolute deviation was 35.7 and 30.9 palette steps, for black vs. white background, respectively, $F(1, 11) = 23.9$, $p < .01$. We found a tendency for greater variability on the black background in several of the experiments in this paper. There was a significant interaction of background and attention, $F(1, 11) = 5.22$, $p < .05$. The effect of attention was slightly greater for the black background than for the white background. On the black background, the average deviation was 40.8 and 30.6 palette steps for simultaneous and successive presentation, respectively. On the white background, these values were 34.7 and 27.1 palette steps, respectively.

The effect of attention on the variability of responses indicates that our manipulation was effective. However, it does not indicate whether attention made the stimuli appear to have a different overall brightness or contrast. To determine whether attention caused a shift in brightness, we calculated the mean shift in response. To calculate mean response shift, for each trial we subtracted the response palette index from the stimulus palette index. Thus, negative numbers indicated that the observer perceived the stimulus to be darker than it actually was and positive numbers indicated that the stimulus appeared brighter than it actually was. The results for all 12 observers are shown in Fig. 3.

Attending to the stimuli did not make them appear brighter. The mean shifts for simultaneous and successive presentation were within one palette step of each other, -5.9 and -4.9 palette steps, respectively ($F > 1.0$). There was a significant effect of background. On the black background, observers perceived the stimuli to be

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[4] We actually analyzed the dispersion of responses in two ways. First, as described in the text, we calculated the average of the absolute values of the deviations in error scores of each trial from the means on the particular attention/background condition. This deviation score is the average of the deviation from the means shown in Fig. 3. Second, we calculated the average absolute deviation around each attention/background condition separately for each of the eight stimulus colors. Both measures yielded the same results in terms of the effect of attention in each experiment.

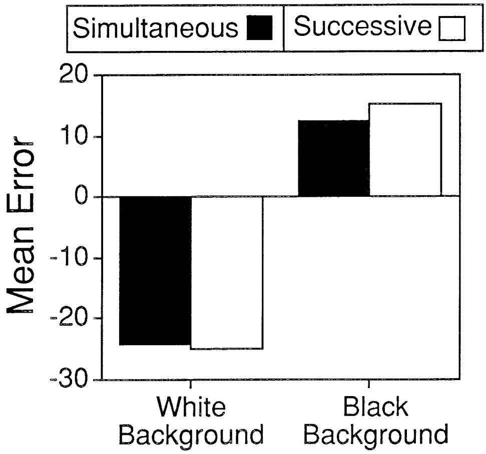

FIG. 3. Experiment 1 mean shift in responses. Negative numbers indicate that the stimulus was perceived as being darker than the true value; positive numbers indicate that the stimulus was perceived as being lighter than the true value.

brighter than they actually were, with a mean shift of +13.8 palette steps. On the white background, observers perceived the stimuli to be darker than they actually were, with a mean shift of −24.6 palette steps. This difference, which is simply the effect of simultaneous brightness contrast, was reliable, $F(1, 11) = 39.7$, $p < .01$.

Finally, as shown in Fig. 3, attention did not influence the contrast of the stimuli. The interaction of attention and background, shown in Fig. 2, did not approach significance, $F < 1.0$. These results are of course different from those obtained by Tsal, Shalev, Zakay, and Lubow (1994). They reported that attention reduced the amount of simultaneous brightness contrast. It would be rash to hastily accept the null hypothesis, and we will return to this critical issue.

Although our prime interest was the effect of attention on perceived brightness, we also analyzed performance on the letter task. Observers were more accurate on the letter identification task with successive presentation. The average number of errors on the letter task was 10.0% vs. 8.5%, for simultaneous and successive presentation, respectively. However, this difference was not reliable, $F(1, 11) = 3.87$, $p = .075$. Nevertheless, the direction of accuracy for the letter task was the same as for the brightness identification task. Hence, the brightness results were not merely due to a trade-off in performance across tasks and attention conditions.

Discussion

The manipulation of attention had a considerable influence on the dispersion of observers' responses. With attention (successive presentation) observers' responses showed less variability than without attention (simultaneous presentation). One way to think of the effect of attention is in terms of the reduction of uncertainty. Reduction of uncertainty is often thought of in terms of response alternatives (e.g., see Fitts & Posner, 1967, p. 99). For example, we might predict that if we had restricted the response alternatives by informing observers that the stimulus would range only within the darkest 1/4 of the palette, the variability of responses would be reduced. Such a reduction in variability would be attributed to the reduction of uncertainty in response processes. The reduction of variability with attention in the present experiment can be thought of as a reduction of uncertainty in perceptual processes and not in response processes. In terms of phenomenology, it may be that on each trial, observers have an impression that the stimulus fell somewhere within a certain range of palette values. With attention, this range is smaller than without attention. We will argue that this reduction of uncertainty about the stimulus brightness is the most pronounced effect of attention.

The background of the monitor (white vs. black) had a significant effect on the mean in observers' responses (i.e., brightness contrast effect). Observers reported the stimuli as being brighter when they were on the black background and darker when they were on the white background. The robust brightness contrast effect is in contrast to the results of Tsal et al. (1994), who found an effect only on a white background.

Significantly, attention had no influence on the mean response. Attended stimuli did not appear brighter than unattended stimuli. Attended stimuli did not seem to have greater or less contrast than unattended stimuli.

We thought that we might be underestimating the effect of simultaneous brightness contrast in this experiment because when the stimulus appeared on a black background (making it appear brighter), the response palette also appeared on a black background, making it also appear brighter. Hence, the background might have affected the appearance of both the stimulus and the palette, at least partially negating the contrast effect. We conducted a follow-up experiment, with 12 additional observers, that was identical to Experiment 1, except that a solid gray rectangle appeared in the center of the monitor. The letter matrix and the palettes appeared on this gray rectangle, but the stimulus disks appeared in the periphery on either a black or white background, as before.

The effect of simultaneous brightness contrast was somewhat greater than in the main experiment. On the black background, the mean error was +21.9 palette steps and on the white background it was −50.1 palette steps (compared to +13.8 and −24.6 palette steps in Experiment 1). More importantly, however, there was no interaction between attention and brightness contrast. The results with the palette on a gray instead of white or black background mirrored the data from Experiment 1 in every respect.

We based our analysis of average deviation and mean response on the error score. The error score was simply the difference between the response palette index and the stimulus palette index. One might question whether the simple difference is the appropriate dependent variable for measuring brightness. Equal steps along our matching palettes are not equal increments in brightness. For example, in cross-modality matching experiments, the general form of the psychophysical function is

$$S = cI^{h/k},$$

where I is the intensity of the stimulus in physical units, S is the sensation that results from the stimulus, c is a scaling constant (see, e.g., Baird & Noma, 1978, Chap. 4). The exponent has two parts: k is the Weber's fraction associated with the stimulus continuum and h is the Weber's fraction associated with the response continuum. In our experiments, the exponent values k and h both relate to brightness and are approximately the same. To the extent that they are similar, they cancel out. Our method could be called ''within-modality matching.'' The reason that ''palette steps'' is a reasonable measure is that a nonlinear transformation of the response scale (e.g., log transformation) would cause the response distributions in Fig. 2 to be skewed. Thus, when the performance around each stimulus is measured (i.e., the distribution of responses in Fig. 3), a nonlinear transformation is not needed and would be inappropriate.

However, our procedure does not render comparisons across different stimuli immune from scaling considerations. For example, the variability of responses was larger with the black background than with the white background. On the black background, the stimulus disks seemed much brighter than they were on a white background. For bright stimuli (i.e., stimuli on the black background), larger changes in intensity are needed to equal increments in brightness in dim stimuli (i.e., those on the white background). The effect of background on the variability of scores (greater variability on the black background) and the interaction of background and attention are probably consequences of the fact that larger increments in brightness are needed to discriminate bright from dim stimuli.

In summary, we were successful in manipulating attention. The variability of responses was less with attention than without attention. We also obtained a robust effect of brightness contrast. However, attending to a stimulus did not make it seem more or less intense in terms of brightness or contrast.

EXPERIMENT 2

In Experiment 1, variability in reporting the brightness of peripheral stimuli was greater when observers had to simultaneously classify a letter at fixation. Similarly, in all of the experiments described by Prinzmetal et al. (in press), the critical stimulus was always in the periphery. In some of the experiments described by Tsal, Shalev, Zakay, and Lubow (1994), the critical stimulus was at fixation and observers' attention was directed to a location in the periphery. Thus, we wanted to determine whether we would replicate the results of Experiment 1 under conditions when the achromatic stimulus was at fixation and the letters were in the periphery.

Method

Experiment 2 was identical to Experiment 1 in all respects, except for the following. The stimulus disk was presented in the center of the monitor, between the two brightness palettes, and the letters were presented in the periphery, at the same location as the achromatic stimulus in Experiment 1. In pilot experiments, we found that it was too difficult to identify the target letter (F or T) in a 3×3 matrix of letters. Hence, we changed the matrix of letters to a string of three letters. The target was always the central letter of the strings, and it was flanked by the letter ''O.'' The three letters were presented in Helvetica 24-point type and subtended a visual angle of 2.76° in width. The distance from the center of the monitor to the inside edge of the letter string subtended a visual angle of 13.6°. The only differences in procedure

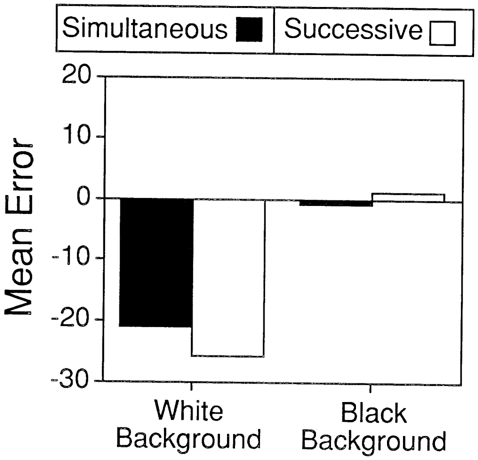

FIG. 4. Experiment 2 mean shift in responses.

from Experiment 1 were that (1) the fixation dot was eliminated (as it may have interfered with the brightness of the disk at fixation) and (2) instead of indicating the location of the achromatic stimulus, observers indicated the location of the letter string.

Results and Discussion

In this experiment there is no independent measure of whether the disks were above threshold since observers indicated the location of the target letters, not the gray disk. However, since the exposure conditions were the same as in Experiment 1, and the disk was located at fixation, we assume that it was above threshold. Observers mislocated the side on which the letters appeared on less than 0.14% of the trials.

As in Experiment 1, we analyzed brightness responses in two ways. First, we examined variability of responses around the mean of each condition. The average absolute deviation was less with successive presentation than with simultaneous presentation, 33.5 vs. 38.2 palette steps, respectively. This difference was reliable, $F(1, 11) = 29.89$, $p < .01$. All 12 observers had less variability for successive presentation than for simultaneous presentation. The effect of the background (white vs. black) was significant, $F(1, 11) = 50.93$, $p < .01$. Observers showed less variability on the black background than on the white background, $F(1, 11) = 50.63$, $p < .01$. The effect of attention was slightly greater on the white background than on the black background. On the black background, the average deviations for simultaneous and successive presentation were 40.9 and 39.6 palette steps, respectively. On the white background, these values were 35.6 and 27.4 palette steps. This interaction was significant, $F(1, 11) = 29.87$, $p < .01$.

To determine whether attention caused any shifts in brightness, we calculated the mean of the responses for each condition. The results are shown in Fig. 4 (recall that negative numbers mean that the response was darker than the stimulus). Attention did not make the stimuli appear brighter. The mean shifts for simultaneous and successive presentation were -10.9 and -12.4 palette steps, respectively, $F(1, 11) = 1.73$.

There was a significant effect of background, $F(1, 11) = 30.84$, $p < .01$. On the white background, observers reported the disk as being darker than it actually was (-23.5 palette steps) and on the black background observers reported the disk as being slightly brighter than it actually was ($+0.13$ palette steps).

There was a small but reliable interaction between background and attention in mean shift, $F(1, 11) = 21.65$, $p < .01$. On the white background, the mean shifts for simultaneous and successive presentation were -20.97 and -25.94 palette steps, respectively. On the black background, the mean shifts for simultaneous and successive presentation were $-.85$ and $+1.105$ palette steps, respectively. This effect is the opposite of that reported by Tsal et al. (1994). They reported that attending to the stimulus reduced the contrast with the background. We found a small but reliable shift in the opposite direction. Though reliable, the increase in contrast with attention (successive presentation) is extremely small, averaging 2.3 palette steps. Because this effect was so small, we were not confident that attention, in general, increases contrast. However, these results reinforce our conclusion from Experiment 1: Attention does not reduce contrast.

Performance on the letter task was nearly identical for simultaneous and successive presentations. The mean errors were 27.8 and 27.2% for simultaneous and successive presentation, respectively. Although this difference was not reliable ($F < 1.0$); there was no indication of a trade-off between the attention conditions and the tasks.

EXPERIMENT 3

In Experiments 1 and 2 we manipulated attention by comparing simultaneous and successive presentations of the letters and gray disk. It is often believed that attention has some spatial specificity: We attend to locations in space or at least to objects at those locations (see, e.g., Tsal & Lavie, 1993). In Experiment 3, we used (nearly) simultaneous presentation and varied the distance between the letters and the gray disk. We assumed that when the letters and gray disk are close together it would be easier to attend to both than when they are far apart.

Method

The procedure was identical to Experiment 1 except for the following factors. In contrast to the previous experiments, the temporal sequence of events was the same on each trial. Because we wanted our observers' attention to be drawn to the location of the letters, the letters appeared first and remained in view for 167 ms. One hundred milliseconds after the onset of the letters, the gray disk appeared and remained in view for 67 ms. Thus, the letters appeared first, but the letters and the gray disk terminated at the same time. Note that the trial was complete before observers had time to initiate and complete a saccadic eye movement.

On half of the trials in a block, the letters and disks appeared on the same side of the monitor, and on half of the trials they appeared on opposite sides, at the same height (i.e., y coordinate) on the monitor as the fixation point. The target letter (F or T) appeared in a randomly determined location in a 3×3 matrix of letters. The distance from the fixation point to the center of the gray disk subtended a visual angle of 9.9°. The distance from the fixation point to the center of the 3×3 matrix

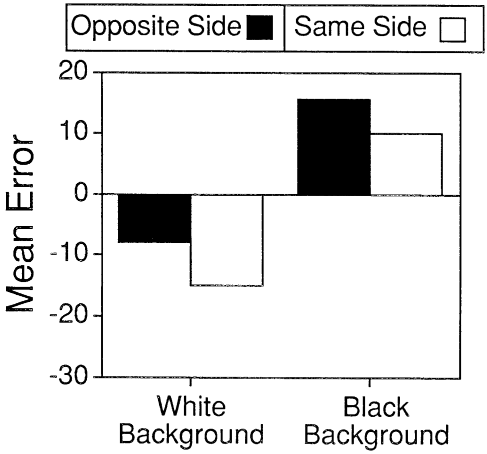

FIG. 5. Experiment 3 mean shift in responses.

of letters subtended a visual angle of 12.4°. Thus, when the disk and letters were on the same side, the distance between their centers subtended a visual angle of 2.76°. When they were on opposite sides, the distance between them subtended a visual angle of 12.66° (2.76 + 9.9). In contrast to Experiment 1, the nontarget letters were always the letter O. The letters were presented in Helvetica 12-point type.

As in Experiment 1, observers indicated the location of the gray disk, as well as its brightness and the identity of the target letter. In contrast to Experiments 1 and 2, we did not alternate the background (white or black) on each block. Instead, half of the observers began with three blocks with the white background and then were tested with three blocks with the black background. The remaining observers began with three blocks of the black background.

Results and Discussion

As in Experiment 1, observers were accurate in identifying the location of the stimulus disks. Observers made location errors on 0.9% of the trials. We infer from the high location accuracy that the stimuli were above threshold.

The attention manipulation had a significant effect on the average absolute deviation of observers' responses. Observers showed less variability when the disk and letters were on the same side than when they were on opposite sides. The average absolute deviation for same- and opposite-side conditions was 34.9 and 37.7 palette steps, respectively ($F(1, 11) = 92.05, p < .01.$). All 12 observers showed this difference between same-side and opposite-side conditions. The variability of responses was greater with the black background than with the white background. The average absolute deviation for the black and white background conditions was 34.9 and 37.7 palette steps, respectively ($F(1, 11) = 7.52, p < .05.$). However, the interaction between background and attention did not approach significance, $F < 1.0$.

Results from the analysis of mean error are shown in Fig. 5. When observers could attend to the disks (same-side condition), they reported them as being slightly darker than when they could not attend to the disks (opposite-side condition). The mean error for same and opposite side conditions was -2.5 and $+3.9$ palette steps, respectively. This difference was only marginally reliable ($F(1, 11) = 5.12$, $p = .045$). This effect could have been due to some lateral interaction between the letters and the target. It is not consistent with the hypothesis that attention makes objects brighter nor that attention reduces brightness contrast.

The background had a significant effect on the mean error. With the black background, observers reported the disks as being brighter than they were ($+12.9$ palette steps). On the white background, they reported the disks as being darker than they actually were (-11.5 palette steps). This difference was reliable, $F(1, 11) = 16.70$, $p < .01$. Thus, we obtained a normal contrast effect. The interaction between background and attention was not significant, $F < 1.0$. Thus, attention did not increase or decrease the contrast.

The percentage of errors on the letter task for same- and opposite-side conditions was 6.08 vs. 5.20%, respectively, but this difference was not reliable ($F(1, 11) = 2.55$).

We had not anticipated that the stimulus in the same-side condition would be perceived as being darker than in the opposite-side condition. Hence, we replicated this experiment (12 observers) with two minor changes. The target letter was in the center of a string of three letters (as in Experiment 2) and we alternated the background every block (as in Experiments 1 and 2). The results replicated Experiment 3 in every way, including a significant effect on the mean error of attention, $F(1, 11) = 35.14$, $p < .01$. The mean error was -10.3 and -6.7 palette steps for same- and opposite-side conditions, respectively. Thus, we feel that finding that the same-side condition was darker than the opposite-side condition was not a type 1 error. We do not have an explanation for this effect but it undoubtedly reflects some kind of spatial interaction between the letters and the gray stimulus disk.

In Experiments 1, 2, and 3 (and in the replications reported with Experiments 1 and 3), an attended stimulus did not seem brighter than an unattended stimulus. In Experiments 1 and 3 (and their replications), attention did not increase or decrease the perceived contrast of the stimulus. These results are contrary to those reported by Tsal et al. (1994), who found that attention decreased simultaneous brightness contrast. The remaining experiments in this paper attempt to reconcile our results with those of Tsal et al. (1994) and also try to delineate conditions in which attention might increase simultaneous brightness contrast (i.e., the small effect in Experiment 2).

EXPERIMENT 4

In our quest to replicate the results of Tsal et al., we conducted over 20 different experiments. We will mercifully report only 5 of them. We concentrated on replicating their Experiments 1, 2, and 3 (Tsal et al., 1994), which were most similar to our experiments. We have reservations about the methodology used in Experiments 4 and 5, and we will discuss these later.

In Tsal et al. (1994) Experiment 1, attention was drawn to a peripheral location by an arrow in the periphery. The interval between the onset of the arrow and the onset of the stimulus was 110 ms. For half of the observers the arrow cue was always valid; that is, it always indicated the appropriate target location. For the remaining observers the arrow cue was always invalid; that is, it pointed to a location without the stimulus. The background was always white.

In Experiments 2 and 3 of Tsal et al. (1994), attention was manipulated in a slightly different manner. In the attend-central condition, the stimulus was in the center of the monitor on every trial in a block. In the mixed condition, the target was in a validly cued peripheral location on two-thirds of the trials. On the remaining trials, a peripheral location was cued, but the stimulus appeared at the fixation point. Experiment 2 used a white background and Experiment 3 a black background. In Experiment 2 (white background), attention significantly reduced simultaneous brightness contrast.

In the experiments by Tsal et al. (1994) described above, there were only four stimuli. Observers were presented with the stimuli during practice and had to memorize labels to associate with the gray levels: 1 for the brightest stimulus, 4 for the darkest, etc. Each condition was preceded by practice that included feedback.

There were many differences between our procedures and theirs. Some of the salient differences were the following. (1) There were differences in the stimuli, e.g., they used small squares whereas we used disks. (2) Their observers responded categorically on a four-point scale instead of responding along a continuous scale. (3) They manipulated attention by using a peripheral spatial cue and/or location certainty, whereas we used various dual-task manipulations. (4) Their observers had to memorize particular responses for the stimulus categories, whereas our response palettes were always in view. In Experiment 4, we attempted to replicate their results by using only four stimuli and a categorical response scale. In Experiments 5, 6, and 7 we attempted to manipulate attention with a peripheral location cue. Finally, in Experiment 8 we explored the effect of requiring observers to learn to assign numbers to the stimuli.

Method

This experiment was similar to Experiment 1 in that we compared simultaneous and successive presentations. The experiment differed from Experiment 1 in only two respects. First, there were only four disk luminance values (instead of eight) and these corresponded to palette values 65, 107, 149, and 190 palette steps (1 being the darkest value on the computer and 254 being the brightest). These values can be converted to cd/m^2 as in Experiment 1. The second difference was that instead of two continuous response palettes, there were two columns of small gray squares, with four squares in each column (see Fig. 6). The top square in each column had the same luminance as the darkest stimulus and the bottom square had the same luminance as the brightest stimulus, etc. The columns were located at the same distance from the fixation point as the palettes were in our previous experiments. The individual squares subtended a visual angle of 1.10° and were separated by a space of 2.76°.

Observers responded as before except that they placed the cursor on the square that most closely matched the brightness of the briefly presented stimulus. Thus, they

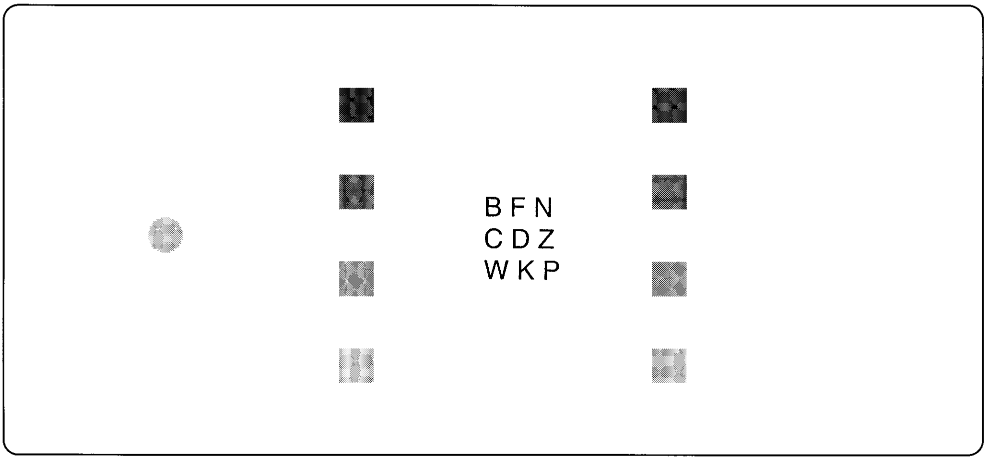

FIG. 6. Response palettes in Experiment 4.

made a categorical response (four-alternative forced choice) instead of responding along a continuum. They indicated the location of the stimulus by using the column of squares on the same side of the monitor as the stimulus.

Results

As in the previous experiments, observers were extremely accurate at locating the stimuli. Location errors occurred on average on less than 0.3% of trials. We interpret this result as indicating that the stimuli were above threshold.

So that our results would be easily comparable to those of the previous experiments, we based our analysis on the error scores, that is, the difference between the response palette index and the stimulus palette index. Although in this experiment the error score for a particular trial is not continuous, averaged over trials for each observer, the average absolute deviation and mean response scores are continuous measures. The variability of responses was significantly greater with simultaneous presentation than with successive presentation. The average absolute deviation was 36.4 and 27.3 palette steps for simultaneous and successive presentation, respectively ($F(1, 11) = 87.93$, $p < .01$). Observers had less variability on the white background than on the black background. The average absolute deviation was 29.5 and 35.2 palette steps for the white and black backgrounds, respectively ($F(1, 11) = 22.75$, $p < .01$). The interaction between background and attention did not approach significance, $F < 1.0$.

The results of the analysis of mean errors are shown in Fig. 7. There was a significant effect of background on the mean shift, $F(1, 11) = 96.7$, $p < .01$. On the black background, observers reported the stimulus as being brighter than it actually was (+15.5 palette steps), and on the white background they reported the stimulus as being darker than it actually was (−11.9 palette steps).

Attention had a small effect on brightness contrast. As shown in Fig. 7, attention increased contrast. On the black background, the mean shifts for simultaneous and

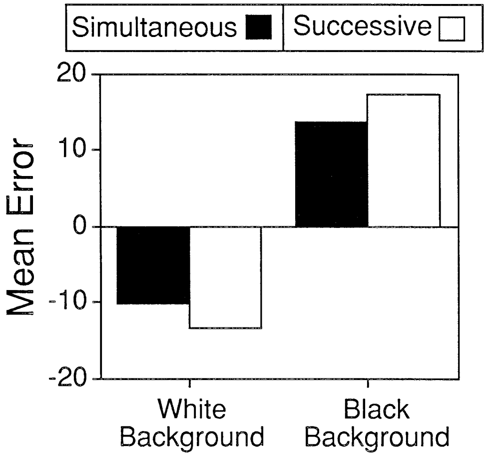

FIG. 7. Experiment 4 mean shift in responses.

successive presentations were +13.6 and +17.4 palette steps, respectively. On the white background, these values were −10.3 and −13.5 palette steps. The interaction between attention and background was reliable, $F(1, 11) = 6.18$, $p < .05$. Because the magnitude of the increase in contrast with attention was small (averaging 3.5 palette steps), we are not confident that attention will increase contrast. Furthermore, as we will discuss below, an increase in contrast might have been due to an artifact inherent in using a categorical response scale. Nevertheless, the results give us confidence that attention does not reduce contrast.

Observers made letter errors on 9.2% of simultaneous trials and 7.7% of successive trials. This difference approached significance, $F(1, 11) = 4.74$, $p = .052$.

Discussion

As in the previous experiments, attention had a significant effect on the variability of responses. Observers had greater variability with simultaneous presentation than with successive presentation.

There was a small but reliable *increase* in contrast with attention, which is the opposite of the effect reported by Tsal et al. (1994). This increase in apparent contrast with attention may indicate that in the domain of contrast, attention increases intensity. However, these results could have been an artifact of the categorization procedure (four-alternative forced choice). We have conducted several simulations of the consequences of categorizing a continuous variable into discrete categories. In these simulations, we assumed that the distribution of responses was normal, the mean response was the same for both simultaneous and successive conditions, and the variance was greater for simultaneous presentations (see Fig. 8). We further assumed that in order to categorize a stimulus into discrete categories, observers set up category boundaries. In our simulations, we have found that even when the means of the continuous distribution are equal, the means of categorized responses may indicate an increase or a decrease in contrast with attention, depending on the parameters of the distributions.

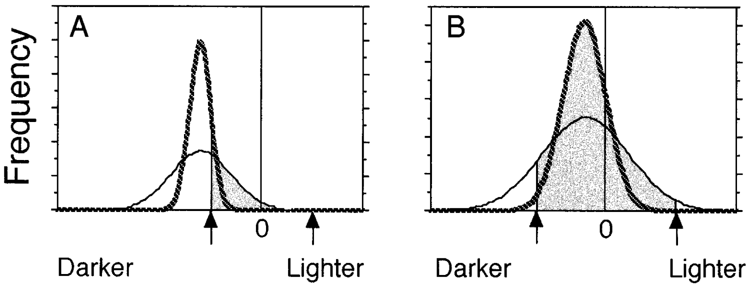

FIG. 8. Hypothetical distributions from experiments on a dark background. Category boundaries for the correct response are marked with arrows and the proportion of correct responses are shaded. In both cases (A and B) the mean shift of the easy attention condition (thick line) and the difficult attention condition (thin line) are identical.

For example, consider the situation illustrated in Fig. 8A. On each trial, observers have an impression of brightness, with the impression falling along a continuous dimension. The distribution of brightness impressions has less variance with successive presentation (thick line) than with simultaneous presentation (thin line). Figure 8 represents trials with the stimuli on a white background so that the means of the distributions are shifted to a darker value. In Fig. 8, we assume that the mean shift was the same for simultaneous and successive presentation. On each trial, observers must categorize the response. In Fig. 8, we assume that if the impression has a value between the two arrows, observers will correctly classify the stimulus. If the impression is darker than the left arrow, observers will respond with a categorical response darker than the stimulus, and so on. Hence, the shaded areas in Fig. 8 represent correct responses. Notice in Fig. 8A that a greater proportion of the simultaneous trials fall into the correct category than do successive trials. Hence, there were more classification errors with successive presentation. Because most of the errors were responses indicating that the stimulus was darker than its true value, the mean of the categorized responses would be darker for successive presentation than for simultaneous presentation, even though the means of the underlying sensory impressions were the same.

The errors that result from categorizing a continuous perceptual dimension into discrete categories are pernicious. Figure 8B demonstrates a situation in which mean errors in the continuous distributions are identical, but the categorized errors indicate more contrast for simultaneous presentation. This outcome results from more of the successive trials falling into the correct category (0 mean error) and more of the simultaneous responses falling into the next darker bin. The only differences between these examples are the variances of the distributions, the overall mean shift, and the size of the response categories (distance between arrows).

The bias resulting from the categorization illustrated in Fig. 8B could account for the results reported by Tsal et al, 1994. What is required is for observers to be more accurate than in the present experiments and for the mean shift to be less. We conducted numerous pilot experiments to see if we could obtain the results of Tsal et al. with categorical responses. For example, we reduced the luminance of the displays with the notion that sensitivity would be greater at lower luminance levels (i.e., Weber's law). We also tried increasing exposure duration and changing the stimulus luminance values so that there would be greater differences between categories. We did not find less contrast with successive presentation. Thus, the bias that can result from categorizing a continuous stimulus is a *potential* cause of the results reported by Tsal et al., and it should be a methodological concern whenever an independent variable can change the variance and mean of a continuous dependent variable. However, because we were not able to replicate the results reported by Tsal et al., we continued varying other experimental parameters in an effort to try to uncover the critical differences in procedures.

EXPERIMENT 5

One of the most obvious differences between the methodology of Tsal et al. and our Experiments 1 through 4 was the method of varying attention. We used dual-task manipulations whereas they used a peripheral spatial cue (e.g., Posner, 1980). Early in the course of this research, Tsal (personal communication, 1995) also suggested that this methodological difference might account for the difference in our results. Hence, Experiments 5, 6, and 7 investigated whether the manipulation of attention with a peripheral spatial cue would cause an attended stimulus to have less contrast than an unattended stimulus. In these experiments, a spatial cue was presented before the stimulus to indicate its location. On 80% of the trials, the cue correctly indicated the target location (valid trials) and on 20% of the trials, the cue indicated a nontarget location.

A second issue concerns the use of a peripheral cue to manipulate attention when accuracy is the dependent variable. Most of the research with peripheral cues has used reaction time as the dependent variable. When accuracy is the dependent variable, there is considerable controversy as to whether attention affects the perceptual representation of the stimulus. For example, Shiu and Pashler (1994) argue that the cue simply provides information as to the likely target location. For example, consider an experiment with four possible stimulus locations. If the stimulus is masked, or very briefly presented, the observer might be uncertain as to which location contained the stimulus. Observers might have a bias to report the information in the cued location. This bias would result in observers being more accurate when the stimulus was actually in this location (valid trials) than when the stimulus was in another location (invalid trials). Thus a difference in accuracy between valid and invalid trials might not indicate that the stimulus was ‘‘clearer’’ when it appeared in a valid location, but rather that observers are more likely to report what they perceived in the cued location. Luck, Hillyard, Mouloua, and Hawkins (1996) provide evidence that at long SOAs (greater than about 200 ms) observers are more accurate with valid trials even when there is no ambiguity of the target location. However, at shorter SOAs, consistent with Shiu and Pashler, they found no facilitation in accuracy. The SOA used by Tsal et al. (110 ms) was in the range where Luck et al. did not find an effect of attention on accuracy. Furthermore, Tsal et al. did not determine if observers were always using information from the target location. It is possible that on some trials observers were using information from the cued location when the target was actually in an uncued location. In our experiments we always asked observers to locate the stimulus. Since we are interested in the phenomenological effect of attention, we

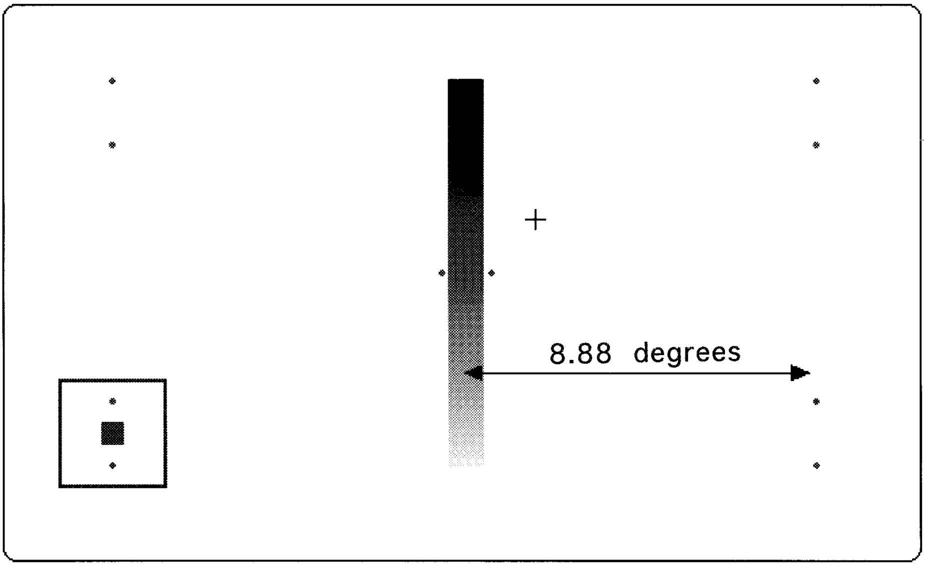

FIG. 9. A sample stimulus from Experiment 5. Note that the cue was red.

wanted to ensure that the stimuli were always above threshold. We presume that if observers could locate the stimulus, they perceived it.

The issue of whether a peripheral cue with a short SOA affects the perceptual representation will not be settled by our experiments. Nevertheless, the results of our experiments forced us to address this controversy. In Experiment 5, we used a peripheral cue and exposure conditions such that observers were nearly 100% accurate at locating the target. Unlike our previous experiment, we found no effect of attention on the variability of responses. In Experiment 6, we masked the gray stimuli and observers had less variability with a valid cue. However, observers did not always accurately locate the target and the results could have been accounted for by supposing that on invalid trials observers were sometimes indicating the brightness of a location that did not contain the target. In Experiment 7, we used a peripheral cue that was nearly identical to one used by Tsal et al. (1996) and found observers to be less variable on valid trials. However, we could not definitively determine that observers always correctly located the stimulus. Our main interest was in the effect of attention on the mean perceived brightness or contrast of an object. Validly and invalidly cued stimuli did not differ in the mean error in any of these experiments.

Method

Throughout each block of trials a single brightness palette appeared in the center of the monitor (see Fig. 9). Also, pairs of gray dots (palette value 127) marked the center of the monitor and each of the four possible stimulus locations. Each trial began with the onset of a cue that marked one of the four stimulus locations. The cue consisted of the outline of a square in red. We were concerned that the cue itself might provide some lateral masking of the stimulus when it appeared in the cued location. Tassinari, Aglioti, Chelazzi, Peru, and Berlucchi (1994) reported that interference from a peripheral cue was minimized when the cue remained in view after the target offset. Hence, in Experiment 5 the cue remained in view until the observer responded.

The gray stimulus appeared 133.3 ms after the onset of the cue and remained in view for 66.7 ms. Thus, the time from the onset of the cue to the offset of the stimulus was 200 ms, which makes it unlikely that observers could initiate and complete a saccadic eye movement. In this experiment and all subsequent experiments, we used a square for a stimulus (instead of a disk) because Tsal et al. (1994) used a square. The square subtended a visual angle of .77°, which was very similar to the visual angle used by Tsal et al. There were eight stimuli that had the same luminance values as did the stimuli in Experiments 1 through 3.

Observers responded in the following manner. They first moved the screen cursor, using a mouse, to the location on the palette that most closely matched the brightness of the stimulus. Then they pressed a button on the mouse to indicate the location of the stimulus. The mouse (Kensington Thinking Mouse) had four buttons corresponding to the four possible stimulus locations (top left, top right, etc.). Thus with one button press, observers indicated the brightness of the stimulus and its location.

There were 80 trials in a block. On 64 of the trials (80%), the stimulus was validly cued; that is, the cue correctly indicated the location of the stimulus. On the remaining trials (20%), the stimulus square appeared in an uncued location. Thus, we confounded two properties that might make a cue effective in summoning attention. A sudden onset of a peripheral cue has been shown to be effective in manipulating attention, even when it is not predictive of the stimulus location, at least with reaction time as the dependent variable (e.g., Jonides, 1981). Second, in our experiments the cue was informative as to the location of the stimulus (as it was in the experiments of Tsal et al., 1994).

Data were collected over six blocks of trials, with three blocks on a white background and three blocks on a black background. As in the previous experiment, when observers made location errors, the computer emitted a two-tone sequence that sounded like a foghorn. As before, observers were given feedback on the precision of their brightness responses at the end of each block. However, to avoid any conscious correction for brightness contrast, observers were not given any feedback as to the mean color shift (as in the previous experiments). There was no letter task in this experiment.

Results

Overall, observers were slightly less accurate in locating the stimulus compared to observers in our previous experiments. Observers correctly located the stimulus on 97.9% of trials. However, in this experiment, there were four possible target locations instead of two locations. Importantly, location accuracy did not vary with the attention condition. The average location accuracy for valid and invalid cues was 98.3% vs. 97.5%, respectively, $F(1, 11) = 1.07$, ns. Thus, observers were equally accurate at locating the stimulus on valid and invalid trials.

There was no effect of attention on the variability of responses. The average abso-

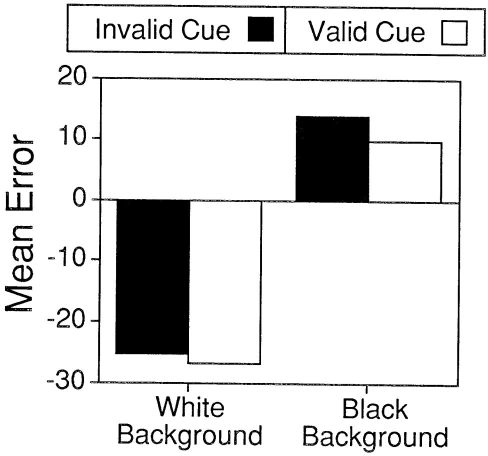

FIG. 10. Experiment 5 mean shift in responses.

lute deviation for valid and invalid trials was 31.7 and 32.8 palette steps, respectively, $F < 1.0$. Furthermore, neither the influence of background nor the interaction of background and attention approached significance (both F's < 1.0).

In terms of mean error, the only reliable effect was that of background (see Fig. 10). When the stimulus was on a black background, the mean shift was $+11.8$ palette steps. On a white background the mean shift was -26.0 palette steps. This difference was reliable, $F(1, 11) = 67.6$, $p < .01$. Attention did not have a significant effect on the mean error, $F(1, 11) = 3.79$, ns. The mean error on valid and invalid trials was -8.5 and -5.7 palette steps, respectively. The interaction between attention and background, illustrated in Fig. 10, did not approach significance, $F < 1.0$.

Discussion

In Experiment 5, under conditions in which observers could accurately locate the stimulus, we found no influence of attention on either the variability of the errors or the mean of the errors. We are not asserting that, in general, with short SOAs and accuracy as the dependent variable, one cannot obtain an effect of attention. However, in this experiment and in several pilot experiments, we failed to obtain such an effect. We ran variations of this experiment including the following: (1) without the gray-dot location indicators; (2) with peripheral arrow cues pointing inward toward the stimulus; (3) with arrows cue that were on the inside of the stimulus pointing outward; (4) with the cue appearing for only a brief exposure, terminating with the stimulus offset; and (5) with different exposure durations. In all of these experiments, the SOAs were fairly short (<150 ms) and observers were quite accurate in localizing the stimulus. In none of these experiments were we able to obtain a difference between valid and invalid trials on either the variability or the mean error in brightness judgments.

We do not consider our failures in obtaining a cueing effect to be conclusive in deciding whether or not attention, manipulated with a peripheral cue and short SOA,

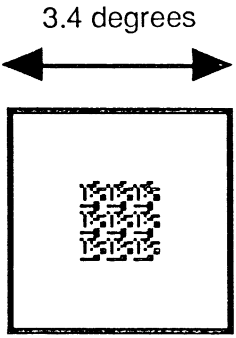

FIG. 11. A sample of cue and mask from Experiment 6. The rectangle cue and the mask were red.

affects the quality of the perceptual representation. Indeed, it is difficult to argue from a null result. However, we can conclusively say that the *mere* use of a peripheral cue does not guarantee that attention will be affected. One needs some evidence to demonstrate that attention is being effectively manipulated in a specific experiment. For example, in Tsal et al. (1994), Experiments 4 and 5, one of two simultaneously presented stimuli was precued. Observers were asked whether the cued or uncued stimulus was brighter. The cue, which surrounded the stimulus, may have affected the brightness of the stimulus via lateral masking. However, there was no evidence that indicated that the cue summoned attention. The mere use of a cue does not guarantee effective manipulation of attention.

EXPERIMENT 6

After our failures to obtain an effect of a peripheral cue at relatively short SOAs (such as used by Tsal et al.), we relaxed our constraint that observers always be accurate in localizing the stimulus. Shiu and Pashler (1994) suggested that when all of the possible stimulus locations are followed by a noise mask, observers might interpret noise in the mask as the stimulus. Presumably, responding to information at the wrong location happens more often after invalidly cued trials than after validly cued trials.

Experiment 6 was nearly identical to Experiment 5 except that the stimulus was immediately followed by masks that appeared in each of the four possible stimulus locations (see Fig. 11). The masks and cue rectangle remained in view until the observer responded. The mask was red (as was the cue) and was created with the standard Macintosh fill pattern number 31.

Results

Overall, observers were 93.4% correct in locating the target. This overall accuracy was not much less than that observed in Experiment 5 and would seem to indicate fairly good performance in a four-alternative forced choice task. Note, however, that 80% of the trials were valid and 20% were invalid. If location errors are divided into valid and invalid trials, observers were 98.0% correct on valid trials and only 76.8%

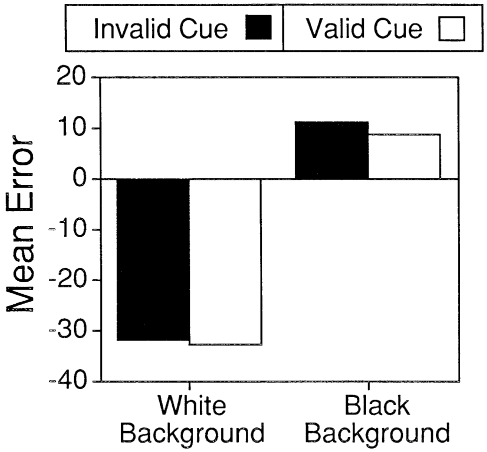

FIG. 12. Experiment 6 mean shift in responses.

correct on invalid trials. This difference was reliable, $F(1, 11) = 40.82, p < .01$. Thus, on a substantial proportion of invalid trials, observers were reporting the brightness of one location when the stimulus was actually at another location. There was also a significant effect of background ($F(1, 11) = 29.59$, $p < .01$) and an interaction of background and attention ($F(1, 11) = 29.99$, $p < .01$). On valid trials, location accuracy was 98.2 and 97.9% for black and white backgrounds, respectively. On invalid trials, location accuracy was 86.6 and 67.0% for black and white backgrounds, respectively.

Given the pattern of location accuracy, it is not surprising that observers had more variability on invalid trials than on valid trials. The average absolute deviation on valid and invalid trials was 36.0 and 41.4 palette steps, respectively ($F(1, 11) = 12.95$, $p < .01$). Note that on a substantial proportion of invalid trials, observers were responding to the brightness of a location that did not contain the stimulus. There were no other significant effects or interactions with average deviation as the dependent variable.

The mean error was reliably affected by brightness contrast (see Fig. 12). On the black background, the mean error was $+9.9$ palette steps, and on the white background, it was -32.4 palette steps, $F(1, 11) = 24.45$, $p < .01$. Neither attention ($F(1, 11) = 1.29$, ns) nor the interaction of attention and background ($F < 1.0$) approached significance.

Discussion

Although the variability of errors with a valid cue was less than with an invalid cue, we do not attribute this difference to attention. Observers mislocated the stimulus on a substantial proportion of invalid trials. Hence, either they were reporting the brightness of a nontarget location, resulting in large random deviations from the actual stimulus brightness, or they did not perceive the stimulus and were guessing. The greater accuracy in locating the stimulus following a valid cue may represent an effect of attention. Alternatively, it could represent a bias to believe that the stimulus would most likely appear in the cued location. The current experiment cannot adjudicate these possibilities. The concern that observers might be mislocating the stimulus is a critical issue in attention experiments. Investigators need concrete evidence that observers are responding to the correct stimulus information on most trials.

We believe that requiring observers to identify the stimulus location is logically superior to other methods of addressing this issue. For example, Shiu and Pashler (1994) and Luck et al. (1996) masked only the stimulus location and therefore there was no ambiguity as to which location contained the stimulus. Logically, this method is not as good as the present method for the following reason. Consider an experiment in which a location is cued, and then a stimulus is presented briefly. A *minute* later, a single mask is presented at the target location and then the observer responds. When the observer responds, there is no ambiguity as to the stimulus location. However, when the stimulus was presented, there was location ambiguity. Observers may have incorrectly localized the stimulus when it was presented, not retaining the information about the item in the correct location. Our method of masking all locations and asking for a location response prevents this problem.

Tsal et al. (1994) did not ask observers to locate the stimuli or otherwise determine if the stimuli were above threshold. Hence, the problem that we have in interpreting our Experiment 6 may also apply to their research. Note that overall, location accuracy was quite high in our experiment (93.4%), yet when broken down into valid and invalid trials, it was obvious that observers were responding to the wrong information on a substantial proportion of invalid trials. In any case, we still did not replicate Tsal et al.'s finding of less brightness contrast with attention.

EXPERIMENT 7

Experiment 7 was one final attempt to replicate the finding of reduced brightness contrast following a valid peripheral cue. Tsal (personal communication) provided us with the computer programs that were used by Tsal and Shalev (1996; Experiment 1) to investigate the effect of attention on line length. The cue they used seemed to be the most effective peripheral cue that we have seen. A trial began with two small horizontally aligned plus signs in the center of the monitor that served as fixation marks. Preceding the presentation of the stimulus, two small horizontally aligned unfilled circles appeared in the periphery. To us it appeared that the fixation marks moved to the periphery and changed shape as they moved. The impression of apparent motion was compelling to us, at least on some trials. We felt that this might be an unusually effective cue because observers first attend to the fixation marks, and then the object that they are attending moves, drawing attention with it. In some respects, the cueing procedure was similar to the reviewing phenomenon described by Kahneman, Treisman, and Gibbs (1992). In an attempt to make our procedure similar to that of Tsal et al., we used only four levels of stimulus brightness and categorical responses, as in Experiment 4 above, and used cues similar to those used by Tsal and Shalev (1996).

Method

Procedure. Each trial began with two small horizontally aligned open circles that served as fixation marks. After 0.5 s these fixation marks disappeared and two dots (the cue) appeared on either the left or the right side of the monitor. The fixation dots appeared to slide horizontally to the left or right. After 133 ms, a stimulus square appeared either between the dots (valid trials) or at the same distance from the fixation dots on the opposite side of the monitor (invalid trials). Following an exposure duration of 67 ms, the screen became blank. One-half second after the termination of the stimulus, a vertical column of four gray squares, which served as a response palette, appeared in the center of the monitor. The dimensions and luminance of the palette squares were the same as in Experiment 4. Also, below the column of four squares, a screen button labeled ‘‘Absent’’ appeared.

To determine whether the stimuli were above threshold, we used a procedure that was slightly different from the one used in the previous experiments. Instead of localizing the stimuli, we included catch trials, i.e., trials without a gray square. Observers responded in the following manner. On target-present trials, they selected and ‘‘clicked’’ the mouse on the palette square that matched the stimulus. On target-absent trials, they clicked on the absent button. The next trial began 0.5 s following the response.

There were 96 trials in a block: 60 valid trials, 20 invalid trials, and 16 target-absent trials. A miss (responding ‘‘absent’’ when a stimulus was present) or a false alarm (responding with a brightness value when the stimulus was absent) resulted in the same feedback as a location error in previous experiments. Following each block, observers received feedback on their absolute precision, but not on their mean error.

Twenty-four observers were tested. The practice procedure was the same as in the previous experiment. Observers were then tested on four blocks of trials, alternating the background between blocks, so that each observer was tested on two blocks with each background. The order of the backgrounds was counterbalanced as before.

Stimulus. The stimulus was a small square that subtended 0.89° of visual angle. The distance from the center of the monitor to the center of the stimulus square subtended a visual angle of 9°. There were four stimulus luminance values, the same as in Experiment 4. The four vertically aligned squares that served as the response palette were of the same dimensions as in Experiment 4. The fixation and cue dots were separated horizontally by 3.1° of visual angle and were approximately 0.2° in diameter. They were white in the black background condition and black in the white background condition.

Results

The average deviation of errors was calculated as before. The variability of errors was significantly greater following an invalid cue than following a valid cue. The average deviation of errors was 29.7 and 33.2 palette steps for valid and invalid trials, respectively ($F(1, 23) = 16.83$, $p < .01$). There was also a significant effect of background ($F(1, 23) = 50.93$, $p < .01$) and a significant interaction of background

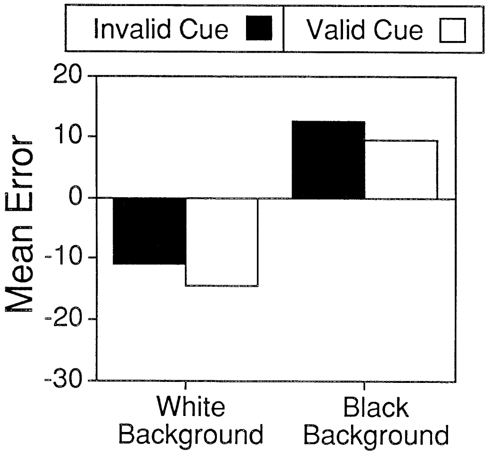

FIG. 13. Experiment 7 mean shift in responses.

and attention conditions ($F(1, 23) = 6.99, p < .05$). The difference between valid and invalid cues was greater on the black background than on the white background. On the black background, the average deviation was 27.7 vs. 33.2 palette steps for valid and invalid trials. On the white background, these value were 26.7 vs. 27.6 palette steps for valid and invalid trials, respectively.

In the present experiment, we used a different procedure to determine whether the stimuli were above threshold. Instead of asking observers to localize the stimulus, we included catch trials. Since we were primarily interested in the phenomenology of attention, we wanted to be sure that our observers perceived the stimuli. The question of whether the stimuli were always above threshold is related to the question of whether the effect of attention on response variability was due to a change in the quality of the perceptual representation or due to some other factor. Alas, we do not have a definitive answer to this question. The hit rate was .996 for valid trials and .983 for invalid trials. Although this difference was small, it was reliable, $F(1, 23) = 22.60, p < .01$. The average false alarm rate was .897, higher than we would have liked. Of course, false alarms cannot be broken down into valid and invalid trials since there is no stimulus on these trials. It is possible that the difference between valid and invalid trials was due to observers using the information from the valid location on invalid trials (i.e., Shiu & Pashler, 1994).

Whatever the cause of the difference between valid and invalid trials, it did not significantly influence the mean error in responses (see Fig. 13). The interaction between attention and background did not approach significance ($F < 1.0$). There is a slight tendency for validly cued stimuli to be perceived as darker than invalidly cued stimuli, -2.8 vs. 0.8 palette steps, which is similar to the results in Experiment 3 and the replication of Experiment 3. However, this effect was not reliable ($F(1, 23) = 2.95, p = 0.10$). As in all of our experiments, there was a significant effect of background on the mean shift in responses ($F(1, 23) = 89.56, p < .01$), which reflects the effect of brightness contrast.

Discussion

In Experiment 7, we obtained an effect of cue validity. Observers had less response variability following a valid cue than following an invalid cue. However, because the detection accuracy (hits and false alarms) was far from perfect, there are several different ways of accounting for this result. On one hand, the cue might have effectively summoned attention so that the quality of the perceptual representation was greater following a valid cue rather than an invalid cue. This account can explain both why the hit rate was higher and why the variability of responses was smaller in the valid condition. In terms of signal detection theory, the d' was higher in the valid condition, but the tendency to believe that a target was present (β, or bias) was the same in both valid and invalid locations.

On the other hand, the results are consistent with an account that assumes that the quality of the perceptual representation was the same in both valid and invalid trials, but observers were more likely to believe that a stimulus was in the cued location. In signal detection terms, d' was identical for valid and invalid trials, but observers had a different bias for cued and uncued locations. If observers occasionally responded with what they perceived to be the stimulus brightness in the cued location on an invalid trial, variability would be greater on invalid trials. Note, however, that this explanation does not account for the results of Experiments 1, 3, and 4 in which observers mislocated the stimulus on a mere 0.18, 0.9, and 0.3% of trials, respectively.

In future research on the effect of peripheral cues, we feel that the type of cue originated by Tsal and Shalev (1996), and used in the present experiment, is well worth exploring. Instead of relying on a peripheral event to summon attention, observers fixate and attend to a central object (i.e., the pair of fixation points). This object then apparently moves to a peripheral location and the question is whether observers will still be attending to it in its new location. As we have stated, there is precedent for such an effect (e.g., Kahneman, Treisman, & Gibbs, 1992).

Regardless of the cause of the facilitation in performance, the stimuli did not seem brighter following a valid cue (i.e., there were no overall positive mean errors). In fact, there was a slight tendency in the opposite direction. Furthermore, the cue did not increase or decrease contrast. As a result of Experiments 5 to 7, and numerous other pilot experiments, we came to the conclusion that the critical difference between our results and those reported by Tsal et al. (1994) were not due to differences in the method of manipulating attention.

EXPERIMENT 8

With Experiment 8, our search for conditions in which attention seems to reduce contrast comes to a close. We are confident that the results of Tsal et al. (1994, Experiment 1 to 3) were not due to the use of a peripheral cue to manipulate attention, nor were they due to the use of categorical responses, per se. One difference between their experiments and our Experiments 1 to 7 is that in our experiments, when observers responded, they had a physically present sample to compare with the briefly presented stimulus. Regardless of whether observers matched the stimulus to a location along a continuously changing palette or to one of four discrete samples, observers were performing a matching task. In the experiments reported by Tsal et al., observers were shown four gray samples before the experiment. They were told to respond with the numbers ‘‘1’’ to ‘‘4,’’ with ‘‘1’’ corresponding to the brightest stimulus and ‘‘4’’ corresponding to the darkest. Thus observers had to rely on their memory of the number code to select their response during the course of the experiment.

The difference in whether observers could select their response by *matching* the brightness with a physically present stimulus or whether observers had to *remember* the brightness values of the response categories could have affected the mean error in the following manner. In the experiments by Tsal et al., observers were given practice with feedback as to the correctness of their responses. This feedback could have affected how observers respond. Suppose, for example, an observer is told before the experiment that ‘‘3’’ corresponds to a certain shade of gray. During practice with the black background, a stimulus corresponding to ‘‘3’’ will look brighter than it actually is (e.g., it might look like a ‘‘2’’). When the observer responds with ‘‘2,’’ however, he or she would be given negative feedback. It would be natural for observers to recalibrate their response scale so that they could be as accurate as possible. In other words, the observer is learning the optimal response mapping to maximize accuracy. The optimal response mapping would reduce the effect of brightness contrast. This account might explain why the brightness contrast effect reported by Tsal et al. was smaller than the effect we obtained. Note that we never gave observers trial-by-trial feedback on brightness accuracy, nor did we inform observers during the experiment as to their mean shift in responses.

The procedure used by Tsal et al. could have induced a reduction in contrast with attention in the following way. Suppose different observers (or observers in different blocks) are run in a condition in which the stimuli were easy to perceive (i.e., with attention) or difficult to perceive (i.e., with attention diverted). Presumably, observers would have been more likely to learn optimal response mapping in the easy condition than in the difficult condition. More optimal response mapping with attention would lead to a reduced contrast effect and a reduced mean shift in responses. This explanation seems more likely because Tsal et al. manipulated their attention conditions either between blocks or between observers, whereas our attention conditions were always mixed randomly within blocks.

In this final experiment, we compared observers in two conditions. In the *matching* condition, observers had the response values physically available to them, exactly as in Experiment 4 (see Fig. 6). In the *memory* condition, observers were shown the brightness responses before the experiment, but they had to rely on their memory of the categories while data were collected. In all other respects, the procedure for the two groups was identical. For both groups, we manipulated attention by comparing simultaneous and successive presentations of centrally presented letters and a peripherally presented gray stimulus. The attention condition was blocked. Finally, before data were collected in each condition, observers received practice with trial-by-trial feedback on their brightness accuracy.

Method

Procedure. The procedure within each trial was identical to that in Experiment 4. Throughout a block of trials, two columns of four squares were present in the center of the monitor. For the matching group, the squares were colored with the four gray values that corresponded to the stimulus (see Fig. 6). For the memory group, the four squares were empty and outlined in black (not shown). Trials began with a fixation dot in the center of the monitor. In the simultaneous condition, a 3 × 3 matrix of letters in the center of the monitor and a small square in the periphery were presented for 67 ms. In the successive condition, the letter matrix was presented first for 67 ms. One-half second following the onset of the letter matrix, a gray square in the periphery was presented for 67 ms. The letter matrix in the center always contained the target letter F or T. Observers responded to the location of the gray stimulus square (left or right), the brightness of the square, and the identity of the target letter. To do this, observers moved the cursor over the appropriate square on the same side as the stimulus was presented and then pressed the left mouse button for an F letter target or the right mouse button for a T letter target.

In contrast to previous experiments, the attention condition was blocked. Observers were tested on two blocks with simultaneous presentation and on two blocks with successive presentation. The blocks alternated with half of the observers in each group beginning with simultaneous presentation. There were 80 trials in each block.

The practice procedure was slightly different than in previous experiments. First, all observers were shown the four stimulus gray values on the screen and the task was explained. Observers then had a minimum of one block of practice with the condition for which data were first collected. Observers were given more practice if needed for acceptable levels of accuracy. During this practice block, in addition to trial-by-trial feedback on location and letter accuracy, observers were given feedback on the accuracy of their brightness judgment. Trial-by-trial feedback was as follows: a location error was signaled by a two-tone sequence that sounded like a foghorn; a letter error was signaled by a brief high-pitched tone; and a brightness error was signaled by a low-pitched tone. While data were collected, feedback was not given for brightness accuracy but was continued for location and letter identification accuracy. Before each subsequent block of trials, observers were given an additional 20 trials of practice, with feedback as in the original practice session. There were 14 observers in each group.

Stimulus. There were four stimulus brightness values, the same as in Experiment 4. Only the white background was tested. The four response palettes were identical to those in Experiment 4 (Fig. 6) except for the following. Above the column of squares the word ‘‘Dark’’ appeared in 12-point Helvetica type. Below the column of squares, the word ‘‘Light’’ appeared. These words were intended to remind the memory group which end of the scale was for the brighter stimuli and which end was for the darker stimuli. For the matching group, the response squares were filled in with the four stimulus gray values; for the memory group, the response squares were empty (white) and outlined in black. The stimulus was a gray square, of the same size and eccentricity as in Experiment 5.

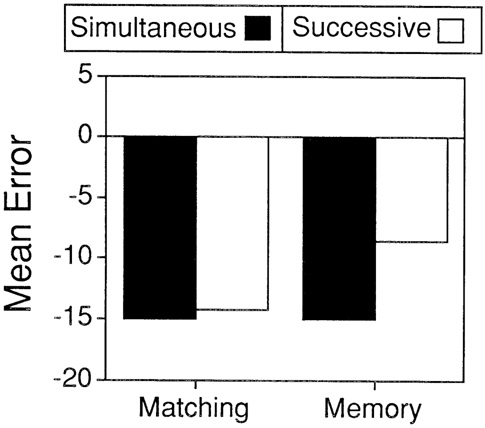

FIG. 14. Experiment 8 mean shift in responses for observers in the matching and memory groups.

Results

Observers were extremely accurate in locating the gray stimulus. Location errors for the matching and memory groups averaged 0.3 and 0.2%, respectively. In terms of performance on the letter task, the groups were equivalent. For the memory group, observers correctly identified the letter on 79 and 98% of trials for simultaneous and successive presentations, respectively. For the matching group, these values were 77 and 96%. In an ANOVA with group as a between-subjects factor, and attention (simultaneous vs. successive) as a within-subject factor, only the main effect of attention was reliable, $F(1, 26) = 86.73$, $p < .01$. The effect of group and the interaction of group and attention did not approach significance (both F's $<$ 1.0).

We analyzed the variability of responses with groups (memory vs. matching) and attention (simultaneous vs. successive presentation) as factors. In this analysis, the effect of attention was reliable, $F(1, 26) = 181.64$, $p < .01$. The effect of attention was similar for the two groups. For the memory group, the average deviation was 29.9 and 18.1 palette steps for simultaneous and successive presentations, respectively. For the matching group, these values were 33.7 and 21.6 palette steps. The interaction of group and attention was not significant ($F < 1.0$).

As shown in Fig. 14, the two groups differed markedly in terms of mean errors in responses. For the matching groups, the mean shift did not differ with attention ($F < 1.0$). The mean shift was -15.0 and -14.3 palette steps for simultaneous and successive presentations, respectively. For the memory group, there was significantly less brightness contrast with attention (successive presentation). The means for simultaneous and successive presentation were -15.0 and -8.5 palette steps, respectively ($F(1, 13) = 6.15$, $p < .05$. Thus, for the matching group, we replicated our previous results—attention did not increase the brightness of the stimuli nor did attention affect the contrast. However, the results with the memory group replicated those of Tsal et al. in that attention seemed to decrease the brightness contrast.

Discussion

For the first time we obtained results that seem to show that attention reduces brightness contrast. However, we attribute this result to a particular aspect of the method. The procedure for both groups was identical except that the matching group could use physically present gray patches on which to base their responses. The memory group, on the other hand, had to rely on feedback that they received in the practice blocks to make the appropriate response. This practice, with feedback, might artifactually reduce the apparent amount of brightness contrast. For example, on the black background, the stimulus gray value ‘‘3’’ might appear more like a ‘‘2’’ (i.e., brighter). To the extent that there is a brightness contrast effect, to obtain optimal performance observers should adjust the response categories appropriately. We assume that this recalibration is facilitated when the stimuli were relatively easy to perceive (successive presentation).

GENERAL DISCUSSION

A fundamental question that concerned 19th century investigators was how attention affected the perceived intensity of an object. The goal of this research was to investigate this question in the domain of brightness. There are three ways in which attention could affect the intensity of an object in the domain of brightness. First, attention could change the absolute brightness of an object, so that, for example, an attended object might seem brighter than an unattended object. Second, attention could change the perceived contrast of an object with the background so that an attended stimulus might have greater (or less) contrast than an unattended object. Finally, attention could affect the processing of a briefly presented object so that the distribution of impressions of an attended object has less variance than that for an unattended object.

We found clear and consistent evidence only for the third proposition. The distributions of sensory impressions have less variance with attention. This finding was most clear in the experiments in which attention was manipulated with a dual task. Note that in these experiments, observers were nearly perfect at indicating the stimulus location, so that the results could not be accounted for by proposing that the attention manipulation simply biased what information observers used (e.g., Shiu & Pashler, 1994). In the domain of brightness, attention clearly affects the perceptual representation. The effect of attention on the variability of sensory impressions was also found by Prinzmetal, Amiri, Allen, and Edwards (in press) in the domains of color (hue), location, line orientation, and spatial frequency.

We interpret the effect of attention on reducing the variability of sensory impressions as being analogous to the reduction in uncertainty that would result from reducing the number (or range) of alternative responses. However, in our experiments, the reduction in uncertainty about stimulus brightness was the result of manipulating attention. Observers had a clearer (less variable) impression about the stimulus brightness when they could attend to the stimulus than when attention was diverted. The results are clearly consistent with a limited-capacity view of attention (e.g. Prinzmetal & Banks, 1983).

Evidence for capacity limits was most clear in the dual-task experiments. In the experiments with peripheral cues, and relatively short SOAs, we had difficulty in obtaining an effect of attention that could unambiguously be attributed to perceptual processes. Our results were consistent with those of Shiu and Pashler (1994), Luck et al. (1996), and Klein, Wylie, and Briand (1996), who found no effects of a peripheral cue at short cue-stimulus SOAs. Our results contradict the claim by Henderson (1996) that Shiu and Pashler's results might be an ''anomalous failure.'' The conditions under which a peripheral cue summons attention, as reflected in accuracy, is an unsettled issue (see, e.g., Cheal & Gregory, 1997; Henderson, 1996). Inconsistent findings with accuracy as the dependent variable contrast sharply with the apparent ease with which a peripheral cue affects reaction time (Klein, Wylie, & Briand, 1996; Posner, 1980; Jonides, 1981). One factor in our apparent difficulty in obtaining clear results with a peripheral cue is that we asked our observers to take their time and to be as accurate as possible. We emphasized accuracy because we wanted our observers to specify the appearance of the stimulus as precisely as possible. Not only were they given accuracy instructions verbally, but near each computer a sign was posted that read, ''Take your time and be as accurate as possible.'' We found it necessary to be emphatic and redundant in these instructions because observers who had previously participated in reaction time experiments often had the mental set that they should respond quickly. It is possible that implicit or explicit instructions to be fast and accurate might explain some of the discrepant findings (see, for example, Henderson, 1996).

The main concern of this research was how attention (however manipulated) would affect the brightness and the contrast of objects. In none of the experiments did attended stimuli seem brighter than unattended stimuli. Thus, we found no support for the notion, expressed by Wundt (and others, see, e.g., Titcheneu, 1908/1973), that attention increases intensity, where intensity is defined as absolute brightness.

Several investigators, more recently, have made claims about the effect of attention on brightness contrast. Festinger, Coren, and Rivers (1970) claimed that attention increased brightness contrast, while Tsal et al. (1994) claimed that attention decreased brightness contrast. The experiments by Festinger et al. confounded exposure duration with attention, assuming that more time simply allowed observers to attend to the stimulus. Of course, exposure duration probably has effects other than its influence on attention. The attention manipulation by Tsal et al. was more sophisticated. They manipulated attention with a peripheral cue. In their Experiments 1 to 3, they compared performance following valid and invalid cues. Observers responded on a 1-to-4 scale, with 1 indicating the brightest stimulus and 4 indicating the darkest stimulus. We found that their results were probably a consequence of their response procedure.

In other experiments (Tsal et al., Experiments 4 and 5), the researchers simultaneously presented two stimuli, one of which was precued. There are two problems with these experiments. First, with this experimental design there was no independent evidence that the cue affected attention. Second, the results that they did obtain could have been due to a spatial interaction between the cue and the stimulus. We found that when the stimulus was adjacent to dual-task letters (Experiment 3), or to a peripheral cue (e.g., Experiment 7), observers reported the stimulus to be darker than when it was not adjacent to anything. This kind of lateral interaction could have accounted for the results of Tsal et al. (Experiments 4 and 5).

With the exception of the memory group in Experiment 8, we never found that attention decreased brightness contrast. In Experiments 1, 3, 5, 6, 7, and 8 (matching group), we found no interaction between attention and brightness contrast. In Experiments 2 and 4, we found very small increases in contrast with attention. However, the effect of attention on contrast in Experiment 4 could be accounted for by the errors that resulted when observers made a categorical response to a continuous stimulus. The increase in contrast with attention in Experiment 2 was only 2.3 palette steps (out of 255 steps in our scale). Thus we found scant evidence that attention changes brightness contrast.

We are not willing to claim that attention never changes brightness contrast. We can think of two situations in which attention might influence brightness contrast. First, Stumpf proposed that attention would only increase the intensity of weak stimuli (see, e.g., Pillsbury, 1906/1973, p. 4). Thus, it is possible that had we used stimuli that had less contrast with the background, we might have found that attention increased intensity (or contrast). A potential problem is that if the stimuli have less contrast, they may occasionally become subliminal. The issue of whether attention can decrease the threshold of weak stimuli is different from the issue of whether attention increases the contrast of above-threshold stimuli. The difference between stimuli that are near threshold, and those that are clearly above threshold, is one that deserves special comment.

As we noted in the Introduction, Ebbinghaus and others were impressed by the observation that attention may make one aware of a very weak stimulus. He gave the example that the faint ticking of a watch might not be noticed unless attended to. Interpreting this observation as evidence that attention increases the intensity of the ticking invokes the following fallacious logic: Increasing the loudness of a watch may make the sound easier to detect. Attending to the sound may make it easier to detect. Therefore attending to the sound is equivalent to increasing its loudness. The issue of whether attention affects the detection of a stimulus is different from the question of whether attention changes the intensity of a stimulus. There are many examples in which attention might influence whether we detect a stimulus, even when the stimulus is quite intense. For example, Sir William Hamilton (1860) recounted the perhaps apocryphal story of Archimedes, who ''was so absorbed in geometrical meditation that he was first aware of the storming of Syracuse by his own death-wound'' (p. 259). The din of the battle was certainly above threshold and the reason that he did not detect the battle probably had little to do with the stimulus intensity. More recently, Mack and Rock (in press) have described situations in which more than 85% of observers might fail to notice a bright stimulus, presented at fixation, if they are attending elsewhere. Thus the effect of attention on detection is different from the effect of attention on the perceived intensity of the stimulus.

The second situation in which attention might influence the perceived contrast of a stimulus is via the effect of attention on perceptual organization. There is considerable evidence that perceptual organization can be influenced by attention (e.g., Peterson, 1986; Prinzmetal & Keysar, 1989; Tsal & Kolbet, 1985). Furthermore, perceptual organization can influence brightness contrast. For example, Agostini and Proffitt (1993) have shown that brightness contrast can occur with items that are not proximal to a stimulus as long as they form a perceptual group with the stimulus. In several clever experiments, Coren (1969) demonstrated that figure–ground organization affects brightness contrast. Figures were judged to have greater contrast than ground. Note that the distinction between figure and ground is not the same as the distinction between an attended object and an unattended object. Although more often we attend to figure than to ground (Wong & Weisstein, 1982), the important distinction between figure and ground has to do with the assignment of a contour to only one region, which often defines the shape of that region (see, e.g., Rock, 1995, p. 114). It seems possible that attention could be shown to influence brightness contrast via the effect of attention on perceptual organization.

The effects of perceptual organization and of attention on near-threshold stimuli aside, we are certain that attention does not affect brightness *contrast.* However, the effects of attention on brightness *contrast* need not be the same as the effect of attention on brightness *assimilation.* In brightness contrast, a stimulus on a white background is perceived to be darker than the same stimulus on a black background. Assimilation has the opposite effect. In terms of stimulus parameters, contrast and assimilation are on a continuum. If a stimulus consists of wide stripes, brightness contrast will occur. However, as the stripes become thinner, contrast will give way to assimilation (e.g., see Helson, 1963). However, assimilation and contrast might not be caused by the same mechanisms. If assimilation and contrast are caused by the same mechanisms, then we would expect that attention would not affect assimilation in terms of mean brightness. However, if assimilation is caused by a different mechanism, then it is possible that attention would affect it as suggested by Festinger, Coren, and Rivers (1970). We are currently examining the effect of attention on brightness assimilation.

Our present findings of no change in brightness or contrast with attention is consistent with our previous findings for color, orientation, and spatial frequency (Prinzmetal, Amiri, Allen, & Edwards, in press). In those experiments, for example, quite large biases in the perception of line orientation were found. Lines oriented near but not quite vertical were reported to be tilted considerably more than they were (see Schiano & Tversky, 1992, for a review of related research). However, the amount of this orientation bias was not affected by attention. Hence, a fairly consistent picture is emerging. Attention reduces the variability of responses but it does not cause biases in perception. The searchlight of attention illuminates in terms of providing more information, but it does not illuminate in terms of changing contrast.

Although a consistent picture is emerging, we doubt that all stimulus domains will behave in the same manner. In the domain of time perception, there are many examples in which attention has a considerable influence. When prospective duration judgments are made, for example, an empty interval may seem longer than a filled interval (‘‘A watched pot never boils’’; see, e.g., Zakay & Block, 1996). The perceived temporal onset of a visual stimulus may be speeded by attention (Stelmach & Herdman, 1991) and the duration of an iconic image may be lengthened by attention (Enns, Brehaut, & Shore, 1996). In the domain of color, we have found only small changes in hue with attention. However, we do not know how attention would influence other aspects of color, such as saturation. Even in the domain of achromatic stimuli, attention might influence the perceived *lightness* of a stimulus (see Footnote 2). Arend and Spehar (1993a) argue that with more complex ‘‘Mondrian’’ stimuli, observers could make either lightness or brightness matches. With stimuli such as those used here, the observers could make only brightness matches (Arend & Spehar, 1993b). Our conclusions apply only in the domain of brightness (see, e.g., Epstein & Brotta, 1986; Epstein & Lovitts, 1985 for effects of attention on constancy).

The influence of attention on phenomenal brightness or contrast—or any other stimulus domain—should impose constraints on models of attention. Consider a model of orientation perception. We might assume that orientation perception is mediated by the output of a population of orientation-tuned detectors. Attention may influence the behavior of individual detectors and therefore the output of the population. One influence of attention may be to increase the number of samples taken by individual detectors before an orientation response is made. The notion that attention works by increasing the number of samples of a stimulus has been suggested by a number of investigators (e.g., Bonnel, Possamaï, & Schmitt, 1987; Luce, 1977; Swets, Shipley, McKey, & Green, 1964). One method of implementing more samples is for neurons in an attended region of space to fire at a higher rate than those in an unattended region. The consequence of obtaining more samples (i.e., increasing sample size) is to reduce variability. A high firing rate would not mean that an attended target line would be brighter than an unattended target line, but that the variability of the final precept would be reduced for the attended stimulus.

Note that increasing the number of samples (by, for example, increasing firing rate) is not analogous to turning up control of intensity. A 30° line is not more intense than a 45° line; blue is not more intense than green. Attention to a blue object does not make it seem green, but increases observers' certainty about the color of the object. Attention to a gray stimulus, in our research, did not change its intensity.

In 1923 Titchener coined the word ‘‘attensity’’ to indicate the phenomenal quality imparted by attention to an object. By attensity, he meant an attribute different from intensity. Our research makes the concept of attensity more precise. When observers attend to a stimulus, they have greater certainty and less variance about the brightness of that stimulus (attensity), but attention does not change the brightness (intensity) of that stimulus.

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