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The Effect of Attention on Phenomenal Length

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Abstract

The effect of attention of the perceived length of briefly presented peripheral lines was investigated. Attention was manipulated by engaging observers in a second concurrent task (letter identification). Observers used the method of adjustment to indicate the length of the stimulus lines. In two experiments it was found that the primary effect of attention was to reduce the variability of line length adjustments. Previously investigators had reported that attention reduces perceived line length (Tsal & Shalev, 1996). A third experiment suggested that these previously reported results might have been the result of a spatial interaction with the cue used to manipulate attention, but not the result of visual attention.

1. Introduction

When we attend to an object, does that object seems shorter, longer, brighter, or dimmer than when we attend elsewhere? In this paper, we explored the effect of attention of the perceived length of briefly presented lines.

The question of how attention affects the appearance of objects dates back at least to the founding of psychology as an independent discipline (see, e.g., James, 1890, chapter 11; cf. Hatfield, 1996). The predominant opinion was that attention increases the "clearness" of a sensory impression, although clearness was not well defined (see, e.g., Woodworth, 1938, p. 694). There was considerable debate as to whether attention increased the intensity of a sensory impression. On the one hand, Wündt, James, Ebbinghaus and others asserted that an attended stimulus seems more intense than an unattended stimulus (see. e.g., Titchener, 1908, p. 213 ff, for a review). On the other hand, Fechner denied that attention increases stimulus intensity stating:

"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 attention upon them." (cited in James, 1980, p. 426).

Nineteenth century investigators commented little on the possibility of attention affecting the perceived length of lines. Münsterberg stated "New experiments confirm that the focus of attention ... does not make a line longer or a tone louder when our attention 'erfasst' (perceives) the image." (Titchener, 1908, p. 215). Titchener, who believed that attention increases stimulus clarity and intensity, commented "It does not seem probably that clearness brings with it any change in extent" (Titchener, 1910, p. 280).

In terms of more recent research, the present investigation was motivated by two lines of investigation. In our lab, we have previously examined the effect of attention in the stimulus domains of color (i.e., hue), location, line orientation, spatial frequency (Prinzmetal, Amiri, Allen, & Edwards, 1996) and brightness/contrast (Prinzmetal, Nwachuku, Bodanski, Blumenfeld, & Shimizu, 1996). In this research, observers had less variability in their judgments when they could attend to the stimulus than when attention was diverted. This reduction in variability could be described in terms of reducing uncertainty about the stimulus identity. Prinzmetal, Amiri, Allen, & Edwards (1996) demonstrated that this reduction in variability was due to perceptual processes, not responses processes. However, attention did not cause any substantial shifts in perception. That is, attended stimuli did not seem different in brightness or contrast than unattended stimuli (Prinzmetal, Nwachuku, Bodanski, Blumenfeld, & Shimizu, 1996; cf. Tsal, Shalev, Zakay, & Lubow, 1994). Also attention did not shift the perception of line orientation or spatial frequency (Prinzmetal, Amiri, Allen, & Edwards, 1996). From these results, one might suspect that attention would make the perception of line length less variable and that attended lines would not be expected to be perceived as longer or shorter than unattended lines.

The second line of evidence is a series of experiments recently reported by Tsal and Shalev (1996). They reported that attended lines were perceived shorter than unattended lines. Thus, attention *reduced* the extent of line length. The goals of the present research were, first, to attempt to replicate the results of Tsal and Shalev using the method that we had previously employed with color, orientation, location, brightness/contrast, and spatial frequency. Second, we wanted to account for the divergent results that we obtained.

1.1 *Recent research*

Most of our previous research on the effect of attention used a dual task procedure. The experiment on orientation perception is a good example of both our procedure and findings. Observers performed two tasks on each trial. One task was to indicate the orientation of a briefly presented line, which was presented at one of four randomly chosen locations in the periphery. Observers indicated the orientation that they perceived by manipulating the orientation of a centrally placed adjustable standard until it matched the orientation of the briefly presented peripheral line. Each trial yielded an error score that was the difference between the orientation of the stimulus and the orientation of the response, in degrees. The other task was to indicate whether a briefly presented matrix of letters contained the target letter C or the target letter G.

Attention was manipulated by having the line and letter matrix appear at the same time (simultaneous presentation) or having the matrix of letters appear first for 100 milliseconds, followed by presentation of the lines (successive presentation). On simultaneous trials, both the letters and line appeared at the same time for 100 milliseconds. On successive trials, the letter matrix appeared first for 100 milliseconds, and following an interstimulus interval of 500 milliseconds, the line appeared for 100 milliseconds. Previous studies have found that simultaneous presentation is more difficult because it requires observers to attend to two objects at the same time (e.g., Eriksen & Spencer, 1969; Hoffman, 1978, 1979; Prinzmetal & Banks, 1983).

Both the mean and variability of the distribution of orientation responses was examined. When observers could devote their attention to the briefly presented line (successive presentation), the variability of orientation responses was considerably less than when they had to concurrently process the letter array (simultaneous presentation). The reduction in variability was interpreted as a reduction in uncertainty about the stimulus orientation. There were also considerable biases in the mean, but these biases were unrelated to the attention manipulation. The biases in responses were related to the stimulus orientation. For example, stimulus lines near, but not quite vertical were reported as being slanted more than they actually were. This effect has been previously reported by a number of investigators (see Schiano & Tversky, 1992, for a review). However, attention had no influence on the mean perceived orientation. As with brightness, color, location, and spatial frequency, attention reduced the variability of observers responses – that is, reduced their uncertainty about the stimulus orientation, but it did not cause a mean shift in perceived line orientation. These results lead us to suspect that attention would not cause a mean change in the perceived length of lines.

The effects of attention that we observed were on stimuli that were clearly above threshold. It was important to objectively determine that the stimuli were above threshold. Suppose that on a small proportion of simultaneous trials (i.e., trials with attention diverted), observers did not perceive the stimulus. On such trials observers would have to guess, and a few such guesses would increase the variability of responses. In fact, Shui and Pashler (1994) have found that the difference in accuracy between validly and invalidly cued trials in a spatial cuing paradigm could be accounted for by trials on which observers did not correctly localize the stimuli (also see Luck, Hillyard, Mouloua, & Hawkins, 1996). We used two different methods to ensure that the stimuli were above threshold. In some of the experiments, observers were asked to locate the stimulus (assuming that one cannot correctly locate an unseen object). In other experiments, we included catch trials. Observers were very accurate at both of these tasks. In the present experiment, we had observers localize the stimuli on each trial.

Contrary to our expectation that attention would not bias the mean line length, Tsal and Shalev (1996) reported that attended lines appeared shorter than unattended lines. They briefly presented vertical lines that were one of five different lengths. In most of the experiments, observers responded with a number corresponding to one of the 5 line lengths ("1" for shortest line, "5" for longest line). Attention was manipulated by using a peripheral cue that indicated the location of the stimulus line (see Posner, 1980). The cue preceded the presentation of a vertical stimulus line by 80 milliseconds and the stimulus presentation was 50 milliseconds. The cue consisted of two small circles that flanked one of two target locations (see figure 4). The cue appeared in target and nontarget locations on an equal proportion of trials. The two salient findings were that (1) peripheral lines were reported as longer than central lines; (2) validly cued lines were reported as shorter than invalidly cued lines.

1.2 *Overview of experiments*

The methods previously employed in our lab differed in many respects from the methods used by Tsal and Shalev (1996) including the following: (1) We used a dual task paradigm to manipulate attention whereas they relied on a peripheral location cue to automatically summon attention to a location (Jonides, 1980; 1983). (2) Our observers adjusted a standard to match a stimulus that had been briefly presented whereas their observers had to memorize a response set. (3) Our observers responded with a continuous response method, whereas their observers responded with a categorical response. (4) We ensured that our stimuli were above threshold. We have previously shown that each of these factors could critically affect the outcome of experiments on the effect of attention (Prinzmetal, Amiri, Allen, & Edwards, 1996; Prinzmetal, Nwachuku, Bodanski, Blumenfeld, & Shimizu, 1996). However, we had not previously investigated how attention affects the perception of line length.

Experiments 1 and 2 used the method of manipulating attention described above. Observers had three tasks. The task that we were most interested was that of indicating the length of a line presented in the periphery. A second task was to indicate the identity of a target letter presented in the center of the monitor. This letter identification task was used to manipulate attention. Finally, to ensure that observers perceived the lines, they had to indicate location of the line. We presumed that if observers could correctly localize the stimulus lines on a high percentage of trials, the lines were above threshold.

Our main comparison in experiments 1 and 2 was the accuracy of line length judgements as a function of whether the letters appeared concurrently with the line (simultaneous presentation) or before the line (successive presentation). Simultaneous presentation ought to render the line length judgement task more difficult than successive presentation because it requires observers to attend to two objects, in different locations, at the same time. In experiment 1, observers made their line length responses with the method of adjustment where length judgments could vary in a (nearly) continuous fashion. In experiment 2, length responses were restricted to one of 5 lengths. We did not find attended lines appeared shorter than unattended lines. Finally, in experiment 3 we explored the possibility that the results reported by Tsal et al. were a possible artifact of a lateral interaction of the stimulus line and attention cue.

2 Experiment 1: Line length with continuous responses

2.1 *Method*

2.1.1 *Observers*. Twelve observers participated in experiments 1 and 2, eight observers participated in experiment 3. No observer participated in more than one experiment. They were recruited from the Psychology Department subject pool at the University of California, Berkeley. Observers' ages ranged from 19 to 31 years. Over all of the experiments reported in this paper, approximately half of the observers were male and half female. All of the observers reported having normal or corrected-to-normal vision.

2.1.2 *Apparatus and stimuli.* Stimuli were displayed on an Apple 15 inch Multiple Scan monitor set in 832 x 625 pixel, 75 hz. mode. The monitor was controlled by a Macintosh Performa 6214 computer.[1] The stimuli appeared as white figures on a black background. The luminance of the background and of the white of the figures (when measured over a solid area) was 5.8 and 110 cd/m^2 as measured with a Minolta Chroma meter (model CS100). Ambient lighting was from overhead florescent lamps. Observers sat 40 cm from the monitor with their heads restrained by a chin rest. At this viewing distance, one degree of visual angle is 22.34 screen pixels.

The stimulus lines and the adjustable standard were 1 pixel wide. The stimuli were vertical lines of one of 5 lengths: 10 pixels (.448 deg.), 25 pixels (1.119 deg.), 40 pixels (1.790 deg.), 55 pixels (2.460 deg.) and 70 pixels (3.130 deg.). The stimulus lines appeared 8 degrees from the center of the monitor (see figure 1). The adjustable standard was a vertical line, in the center of the monitor. Its length was set at the beginning of each block to a random value between 1 pixel and 80 pixels in length. During a trial it could be adjusted to be any length between 1 and 80 pixels. The initial length of the standard on subsequent trials was the fianl length on the previous trial.

Insert Figure 1 about here

The letters in the 3 x 3 matrix were in Helvetica 12 point type. The matrix of letters occupied a square subtending a visual angle of approximately 1.790 degrees per side. The target letter (F or T) was chosen randomly on each trial, and it appeared at a randomly chosen location in the matrix on each trial. The nontarget letters were randomly chosen from the remaining letters in the alphabet.

2.1.3 *Procedure.* Each trial began with a fixation dot in the center of the monitor. On simultaneous trials, the fixation dot was replaced by the simultaneous onset of a 3 x 3 matrix of letters in the center of the monitor and a vertical line at one of two locations in the periphery (see Figure 1). The exposure duration of the letters was 67 milliseconds, and the exposure duration of the line was 33 milliseconds. On successive trials, the letter matrix first appeared for 67 milliseconds. One-half second after the onset of the matrix, the vertical line appeared for 33 milliseconds. Observers did not know in which of the two locations the stimulus line would appear so they could not move their eyes in anticipation of the line location. For both kinds of trials, one-half second after the offset of the stimulus line, an adjustable standard line appeared in the center of the monitor and remained in view until the observer responded.

Observers had to respond to three aspects of the stimulus on each trial: (1) indicate whether the stimulus line appeared in the left or right visual field; (2) indicate whether the target letter was an F or a T; (3) indicate the length of the stimulus line. The responded as follows. First they adjusted the length of the standard line to match the briefly presented line. The standard line was adjusted by moving a mouse up and down. Moving the mouse up made the standard line longer, moving the mouse down made it shorter. After adjusting the standard line, observers indicated the location of the briefly presented line (left or right visual field) and the identity of the target (F or T). The mouse had 4 buttons, in a 2 x 2 arrangement. Observers pressed one of the top buttons if the stimulus was an F, one of the bottom buttons if it was a T. They were to use one of the left buttons if the stimulus had appeared in the left visual field, one of the right buttons if it had appeared in the right visual field. For example, pressing the top right button indicated that the stimulus line had appeared on the right, and the target letter was a T. Thus one button press (after adjusting the standard line) indicated the stimulus line length, its location, and the identity of the target letter.

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 line location, the computer emitted a 2-tone sequence that sounded like a foghorn. Observers were not given trial-by-trial feedback on length accuracy, because we wanted them to give priority to the letter task to ensure an effective manipulation of attention. However, between blocks they were told their average absolute deviation between the stimulus length and response length for that block. They were not given any information about the direction of their length errors.

Before data were collected, observers were given the following practice. They were first shown the stimulus with an exposure duration of 0.5 seconds (both letters and lines). After they demonstrated that they understood and could perform the task, the exposure duration was successively lowered, over approximately 30 trials, until it was 67 milliseconds for the letters and 33 milliseconds for the lines. Observers then had a minimum of 1 block of 80 trials of practice at these exposure durations.

Data were collected over 6 blocks of trials, 80 trials per block. Half of the trials in a block used simultaneous presentation and half used successive presentation. Also, within each block the 5 stimulus line lengths were tested equally often with simultaneous and successive presentation. The order of trials within a block was random. The target letter (F or T) and the line location (left or right) was randomly determined on each trial. Data were collected over 6 blocks of trials. The experiment lasted approximately 1 h.

1.2 *Results and discussion*

1.2.1 *Results.* An error score was calculated for each trial. The error score was the difference, in pixels, between the response length and stimulus length (note 22.34 pixels = 1 degree). A positive error score indicates that the response was longer the stimulus, a negative error score indicates the opposite.

Insert Figure 2 about here

The distribution of error scores, including all observers and trials, is shown in figure 2. There are three trends to note in the data. First, the variability of responses is greater with simultaneous presentation. Second, there appears to be a shift in mean so that the stimuli appeared shorter than they were. Finally, the shift is less for successive presentation. These three aspects were confirmed by statistical analysis.

In order to analyze the change in variability of scores, we calculated, for each observer and condition, the average absolute deviation of each score from the mean error. The average absolute deviation is preferred as a measure of variability because it is more robust to violations of assumptions of analysis of variance than the standard deviation (Keppel, 1991, p. 102). The average absolute deviation for simultaneous and successive presentation was 9.3 pixels and 8.1 pixels, respectively. Eleven of twelve observers had less variability with successive presentation and the difference was reliable by ANOVA, $F(1,11) = 5.76$, $p < .05$.

There was a small shift in the mean error. Eleven of 12 observers adjusted the standard, on average, to be shorter than the stimulus. The mean length error was -3.11 pixels. This shift in mean was smaller with successive presentation. The mean shift for simultaneous and successive presentation was -5.64 and -.59 pixels, respectively, $F(1,11) = 40.93$, $p < .01$. Thus observers were more accurate in setting the length of standard line when they could attend (successive presentation) both in terms of variability and central tendency (mean error).

Observers were slightly more accurate at letter identification with successive than simultaneous presentation (91.1% vs. 90.1%), but the difference was not reliable ($F < 1.0$). From these data note that there is no evidence that observers were trading off performance on the letter and length tasks across conditions. We assumed that if observers could correctly locate the stimuli, they were above threshold. Observers were extremely accurate at localizing the line stimuli, averaging 99% correct (98.9% for simultaneous presentation and 99.1% for successive presentation).

1.2.2 *Discussion*. As in our previous research, the variability of responses was less with attention (successive presentation) than without attention (simultaneous presentation). We did not find that attended lines were perceived as shorter than unattended lines, as reported by Tsal and Shalev (1996). Rather, we observed a small tendency in the opposite direction; attended lines were perceived as longer than unattended lines.

Our finding that attended lines wereperceived as longer than unattended lines should be understood in the context of the distribution of responses (see figure 2). Overall, observers had a small tendency to underestimate the length of lines. We do know the cause of this underestimation. One possibility is that it was due to a kind of framing effect in that the stimulus lines were presented in the periphery of a monitor that was wider than it was tall, similar to framing effects reported by Kunnapas (1955). Even if the monitor had been square, Prinzmetal and Gettleman (1993) have shown that shown that the anisotropy that causes the vertical-horizontalillusion occurs, in part, because the binocular field of view is asymmetrical. The underestimation in the present experiment was reduced with attention (i.e., successive presentation). Previous invesgators have found that attention can reduce various line length and size illusions. For example, Coren and Girgus (1972) found that the Mueller-Lyer illusion was reduced merely with instructions to attend to the central shaft (also see Gardner & Long, 1961). There is ample precedent for attention to affect length and size illusions (e.g., Coren & Porac, 1983; Shulman, 1992; Tsal, 1984).

A second possibility is that attention to the center of the letter matrix caused the lines to be perceived as shorter. Prinzmetal and Keysar (1989, experiment 2b) demonstrated that attention could affect the perceived distance between stimuli. To test whether attention to the letters caused the lines to be perceived as shorter, we ran an additional 12 observers in an experiment identical to experiment 1 except that they were told to ignore the letters in the center of the monitor. Under these conditions, observers did not underestimate the line lengths; the mean response (+1.1 pixels) was not reliably different from 0. Furthermore, the difference in mean length was not significantly different for simultaneous and successive presentation ($F(1,11) = 1.36$). The mean lengths in the follow-up experiment were 1.3 and .9 pixels for simultaneous and successive presentation, respectively, .

Whatever the cause of the small underestimation of line length, we did not replicate the findings of Tsal and Shalev. As we pointed out, there were many differences between their experiments and ours. For example, their observers made categorical responses, that is, they responded with a category label that corresponded with one of the 5 stimulus lengths whereas in experiment 1, observers made their responses by adjusting a standard in a (nearly) continuous manner. We have previous shown that forcing observers to categorize a continuous dimension (e.g. line length) into discrete categories can cause considerable distortion of the results particularly if condition means and variances differ (Prinzmetal, Nwachuku, Bodanski,Blumenfeld, & Shimizu, 1996). In experiment 2 we replicated experiment 1, but observers' responses were restricted to one of 5 responses. We wanted to determine whether categorizing line length into discrete categories would lead to a pattern of results more like those reported by Tsal and Shalev.

3 Experiment 2: Line length with categorical responses

3.1 *Method*

The method was identical to experiment 1 except for the following factors. As the observer moved the mouse up or down to adjust the standard, the standard could only assume one of five line lengths (corresponding to the stimulus length). The standard line would jump in length from stimulus size to stimulus size. When it changed sizes, the computer would emit a "click." Also, just below the adjustable standard was a number from 1 to 5 that corresponded to the size of the line, '1' being the shortest, '5' the longest. (Helvetica 12 point type). The digits were intended to simulate the categorical nature of Tsal and Shalev's procedure where observers responded one of 5 keys on a keyboard.

3.2 *Results and discussion*

3.2.1 *Results.* Error scores were calculated as in experiment 1 and the distribution of these errors is shown in figure 3. Note that positive errors indicate that the stimulus was perceived as longer than it was and negative number indicate that the stimulus was perceived as shorter than it was. The same three trends observed in the data of experiment 1 are present in experiment 1: (1) There is less variability with successive presentation; (2) There is a very slight shift so that the stimuli were perceived as being shorter than they actually were; (3) The tendency to perceive the lines as shorter was less with successive presentation.

Insert Figure 3 about here

We measured the variability of responses as in experiment 1. For each observer in each condition we calculated the average absolute deviation of errors from the mean error. The average absolute deviation was 9.1 and 7.1 pixels for simultaneous and successive presentation, respectively. This difference was reliable in an ANOVA, $\underline{F}(1,11) = 121.5$, $\underline{p} < .01$. All twelve observers had less variability with successive presentation.

Observers had a slight tendency to underestimate the length of the stimulus. This underestimation averaged only 3.4 pixels, but each of the observers showed this effect. The underestimation was significantly greater with simultaneous (5.6 pixels) than successive presentation (1.2 pixels), $\underline{F}(1,11) = 36.20$, $\underline{p} < .01$.

Performance in terms of the letter task and location accuracy was almost identical to experiment 1. Observers were slightly more accurate on the letter task with successive presentation. The average percent correct for the two conditions was 89.8% and 90.7% correct, for simultaneous and successive presentation, respectively. This difference was not significant, $\underline{F} < 1.0$. In localizing the line, observers were 98.5% and 98.9% correct for simultaneous and successive presentation, respectively.

3.2.2 *Discussion*. Despite the fact that observers made categorical responses, the results were nearly identical to experiment 1. Categorizing a continuous stimulus into discrete categories has the *potential* for biasing the results (see e.g., Prinzmetal, Nwachuku, Bodanski, Blumenfeld, & Shimizu, 1996). However, this was apparently not a problem in the present experiment. It was suggested to us that one problem with both experiments 1 and 2 was that "Ss experience a range of lengths as part of the response production that intervene between the stimulus and the response and could distort the original perception of length" (Tsal, personal communication,September, 1996). To test this possibility, we ran an additional 6 observers in an experiment nearly identical to experiment 2 except that observers responded by selecting a number from 1 (for the smallest line) to 5 (for the longest line). The results were nearly identical to experiments 1 and 2. Observers had a tendency to underestimate the stimulus line length. The underestimation was significantly greater with simultaneous (6.8 pixels) than successive presentation (1.3 pixels).

4 Experiment 3: Effect of the "cue" on line length

A salient difference between the procedure used by Tsal and Shalev and our own is that they used a peripheral location cue to summon attention. The cue consisted of 2 small circles that flanked the line stimulus. The line stimulus appeared immediately after the cue.

Insert figure 4 about here

It occurred to us that the cue itself might cause the stimulus line to appear shorter than it was, independent of any affect it has on attention. In valid trials, the cue would immediately flank the stimulus, whereas on invalid trials, the stimulus line appeared by itself (see figure 4). Note that although the cue preceded the stimulus, because factors such as screen (phosphor) persistence, visible persistence, etc. it may have been as if the cue and stimulus were presented simultaneously.[2] Experiment 4 tested the hypothesis that a line segment, surrounded by two dots (figure 4a), might seems shorter than a line presented alone.(figure 4b). A line flanked by 2 dots might be considered as a kind of reduced "arrows-in" Müller-Lyer illusion.

4.1 *Method*

The experiment compared the perceived length of lines in two conditions. In the 'blank' condition, the stimulus lines were presented in the periphery, exactly as in the previous experiments, for 34 milliseconds. In the 'cued' condition, the lines were flanked by two small circles (see figure 4). Note that the term 'cued' does not mean that the dots summoned attention to the line. To ensure that the dots did not function to draw attention to the peripheral location, the stimulus line appeared *first* by itself for 34 milliseconds. The dots appeared immediately after the stimulus line disappeared and remained in view for 67 milliseconds. Half of the trials in a block were the blank condition and half the cued condition. The dots were drawn to be similar to the cues used by Tsal and Shalev. The distance between the dots subtended a visual angle of 2 degrees.

The method was similar to experiment 1 in that observers adjusted a central standard in a continuous manner, with a mouse, to match the length of a briefly presented peripheral stimulus line. When the central standard matched the briefly presented line, they indicated the location of the line (left or right visual field) by pressing one of two mouse buttons. There was no dual task or attention manipulation of any kind.

Following practice, which was identical to experiments 1 and 2, data were collected in 4 blocks of 80 trials per block. There were 8 participants. In all other respects, the experiment was identical to experiments 1 and 2.

4.2 *Results and discussion*

Each observer perceived the 'cued' (with dots) lines as shorter than the blank lines (without dots). The mean length error with the dots was -.8 pixels with the dots and 5.3 pixels without the dots. This difference was reliable with ANOVA, $\underline{F}(1,7) = 16.54$, $\underline{p} < .01$. The dots surrounding the lines caused these lines to be perceived as shorter than lines without the dots. It is unlikely that the dots caused attention to be summoned to the stimulus line position preparing the observer because they were actually exposed after the lines.

Insert figure 5 about here

In terms of response variability, the dots made performance worse than without the dots (see figure 5). The absolute average deviation was larger with the dots (6.4 pixels) than without the dots (5.0 pixels). This greater variability with the dots was true of each observer and was reliable, $\underline{F}(1,7) = 93.45$, $\underline{p} < .01$. The more variable performance in the cued condition (with the dots) probably was due to lateral masking caused by the dots. Furthermore, the effect of the dots on variability is further evidence that the dots did not summon attention in this experiment. If the dots had summoned attention, we would expect less variability with the dots than without.

As in the previous experiments, observers were extremely accurate at location the stimulus line. Percent correct on line localization was over 99% in both conditions indicating that the stimuli were well above threshold.

5. General Discussion

Attention had a clear effect on the perceived length of lines in experiments 1 and 2. There was less variability when observers could attend to the stimuli (successive presentation) than when observers were engaged in an attention demanding concurrent task (simultaneous presentation). This result is consistent with previous findings for color (hue), location, line orientation, brightness/contrast, and spatial frequency (Prinzmetal, Amiri, Allen, & Edwards, 1996; Prinzmetal, Nwachuku, Bodanski, Blumenfeld, & Shimizu, 1996).[3]

We did not replicate Tsal and Shalev's (1996) finding that attended lines are perceived shorter than unattended lines. Rather we found a small effect in the opposite direction: Overall there was a tendency to underestimate the line length, but this tendency was less with attention.

In the last experiment, we tested the possibility that the cue may have affected the perceived line length independent of any influence that it had on attention. We compared the lines alone, with the lines flanked by 'cues' (small circles). However, to ensure that the 'cues' were not summoning attention to the line location, they appeared after the lines. The stimuli with cues appeared shorter than without cues. The vagaries of inductive logic are such that one can not be certain that the mere presence of the small circles caused lines in Tsal and Shelav's (1996) valid condition to appear shorter. However, our results indicate that their results could have been due to a spatial interaction of the 'cue' and stimuli. Caution should be exercised in interpreting experiments that manipulate attention with spatial cues.

Tsal and Shelav (1996) proposed the "attentional receptive field" hypothesis to account for their finding that attended lines appear shorter than unattended lines. Their theory was that unattended stimuli are perceived with mechanisms with larger receptive fields than attended stimuli. If a stimulus line falls in larger receptive field, the output of this mechanism is "rounded up" so that a central processor presumes the line extended to the end of the receptive field. With attention, receptive fields are smaller, hence this rounding up process does not cause attended lines to appear longer. The research reported here challanges the empirical basis of the attentive receptive field hypothesis, and hence a different theoretical framework for the effect of attention is warrented.

We have found that the main influence of attention was to reduce the variability of responses. In various stimulus domains, including color, location, line orientation, brightness, and now line length, when observers attend to a stimulus their responses show less variability than when attention is diverted (Prinzmetal, Amiri, Allen, & Edwards, 1996; (Prinzmetal, Nwachuku, Bodanski, Blumenfeld, & Shimizu, 1996). One way of conceptualizing the reduction in response variability is that with attention observers have less uncertainty about the stimulus length. From this view, attention reduces the observer's uncertainty about the precept, but does not create biases in perception (Maddox & Ashby, in press).

A general way to consider the effect of attention of response variability is to consider the effect of attention as providing of more samples (i.e., "glimpses") or multiple observations of the stimulus (e.g. Bonnel, Possamaï, & Schmitt, 1987; Luce, 1977). Thus the effect of attending to a stimulus is analogous to increasing the exposure duration: With attention observers have more opportunity to gather information about the stimulus line length (Swets, Shipley, McKey, & Green, 1964). This view of attention has three advantages. First, it predicts that response variability will be reduced with attention without predicting that the observers attentional state will cause a bias in perception (e.g., attended lines to be perceived as shorter). Second, the multiple samples approach accounts for the observed effects regardless of the mechanism of length perception. For example, the mechanim that mediates the perception of line length might be similar to hyper-complex cells tuned to particular line lengths. Alternatively, the perception of length might be mediated by a localization mechanism: The visual system first locates the line ends and then calculates the distance between them. In either case, we would predict that multiple glimpses would provide more information and less variability in responses.

Finally, the multiple samples account can be implemented easily in neural hardware. One effect of attention is for neurons, when activated, to have a higher firing rate when in an attended region of space than when when in an unattended region of space (see Colby, 1991 for a review). A second method to implement the more samples hypothesis is for detectors to be recruited for the attended region of space by shifting their receptive fields to included the attended region of space. Conner, Preddie, Gallant, and Van Essen (in press) have found cells in V4 that behave in this manner. The result of either of these neural mechanisms would be to make the final response less variable. In information terms, such attention mechanisms would reduce uncertainty about the stimulus.

In summary, we investigated the effect of attention on perceived line length using a dual task procedure. The main influence of attention was to reduce the variability of responses. We found that previous claims that attention causes lines to be preceived as being shorter were probably due to a spatial interaction of the stimulus and the spatial cue used to direct attention.

Footnotes

1. The computer programs that were used in this research can be obtained from the authors. They require a 2 or 4 button programmable mouse, such as a Kensington Thinking Mouse™. To receive the

programs, please send a 3.5 inch double-density disk and a self-addressed stamped envelope.

2. We are grateful to Yehoshua Tsal who provided to us one of the computer programs used to collect data in the experiments reported by Tsal and Shelav. Without actually seeing the experiment, we probably would not have come up with the hypothesis tested in experiment 3.

3. The effect of attention of the variability of responses also appears to be consistent with the results of Tsal and Shelav (1996). However, they did not analyze the mean and variability of responses so it is difficult to be certain. Rather, they separately analyzed the proportion of the following types of responses: correct responses, overestimations, and underestimations. The problem with these analyses is that they are not independent. For example, if attend and unattend conditions differ in the proportion of correct responses (more correct responses with attention), then the proportions of responses the other categories also have to differ.

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Figure Captions.

Figure 1. Sample of a stimulus in experiments 1 and 2. The figure is drawn to scale. In the simultaneous presentation condition, the onset of the line and the letter matrix coincided. In the successive presentation condition, the matrix appeared .5 seconds before the onset of the line. In both conditions, the exposure duration of the line and letter matrix were 33 and 67 milliseconds, respectively.

Figure 2. The distribution of line length errors in experiment 1. Length error is the difference, in pixel units, between the stimulus and response lengths. Positive numbers indicate that the response was longer than the stimulus, negative numbers mean that the response was shorter than the stimulus.

Figure 3. The distribution of line length errors in experiment 2. Note that there were the same number of observations in experiments 1 and 2, but because of the categorical nature of the responses in this experiment the response bins are 15 pixels wide (i.e., the difference between the stimulus line lengths).

Figure 4. Sample "cued" and lines-alone stimuli from experiment 3.

Figure 5. The distribution of line length errors in experiment 3.

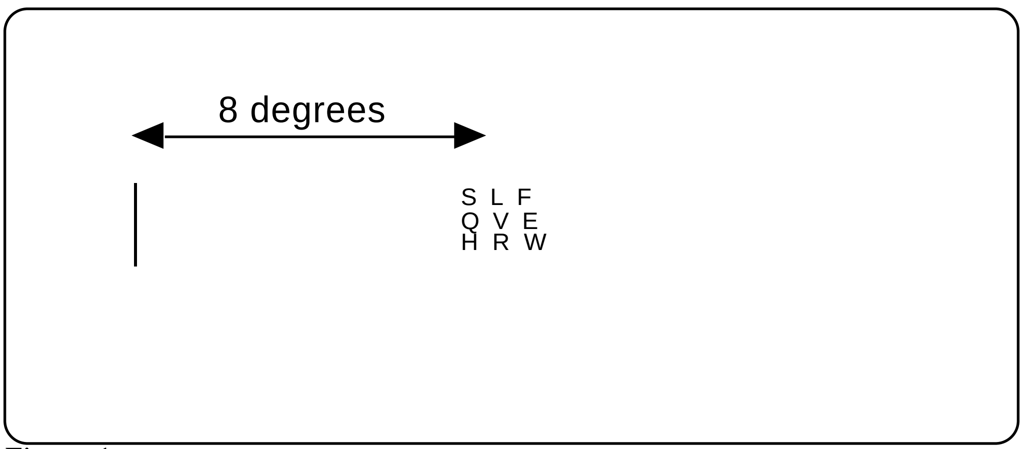

Figure 1

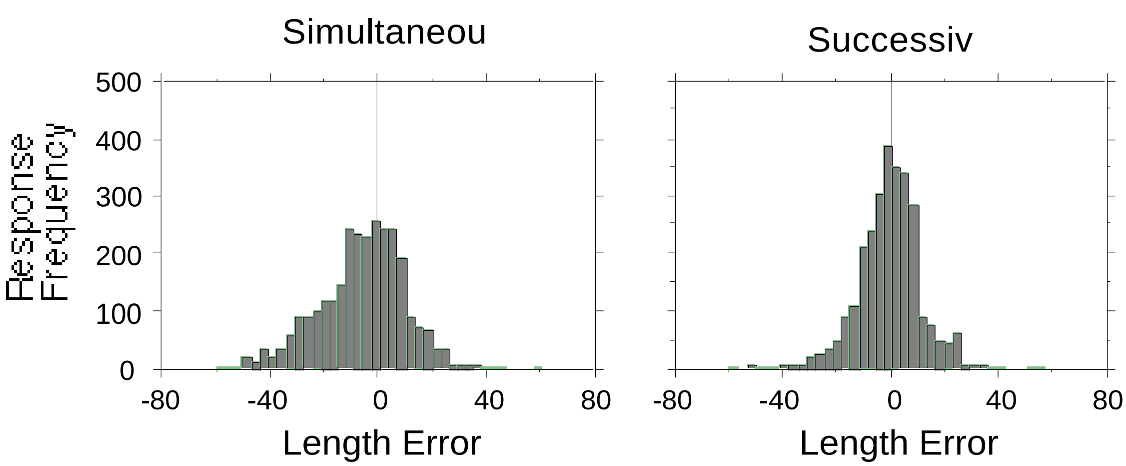

Figure 2

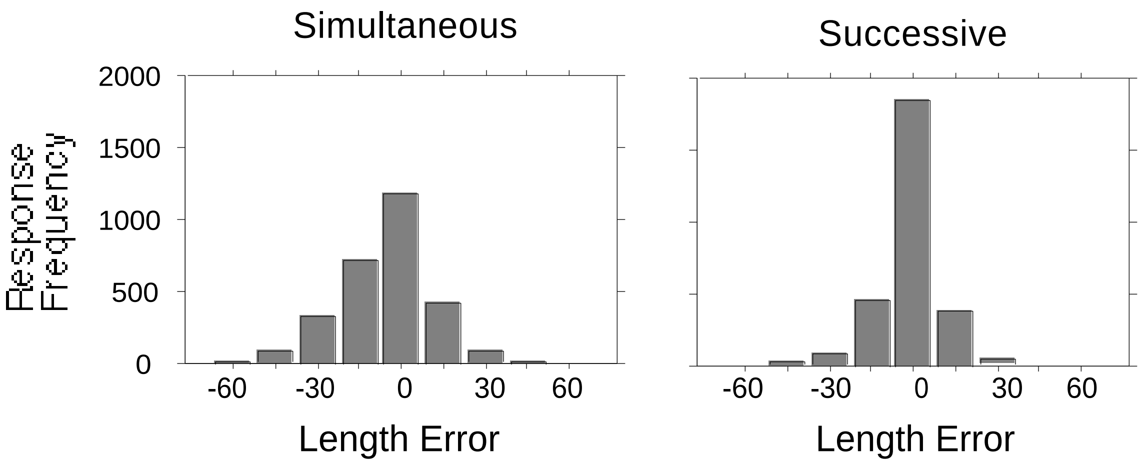

Figure 3

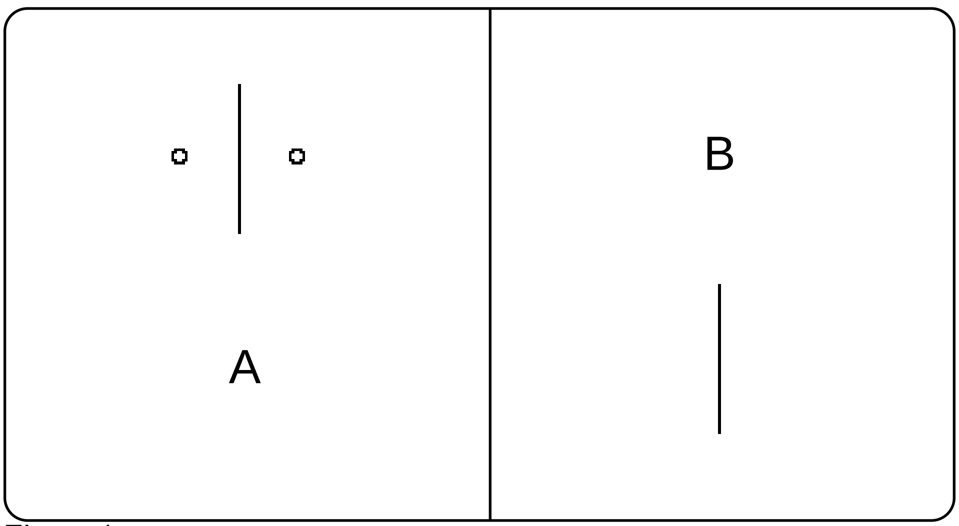

Figure 4

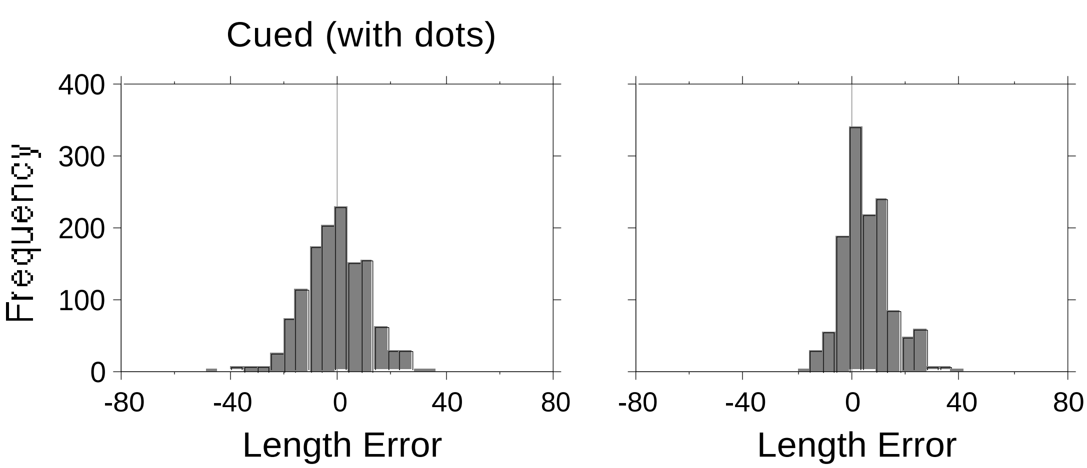

Figure 5