

# Location-Specific Target Expectancies in Visual Search

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Observers searched for local target letters in global letter configurations. Different targets appeared with different frequencies in the different locations of the configurations. Experiment 1 showed that in each location, the target that was presented there more frequently was detected faster. Experiment 2 indicated that this location-specific target probability effect was due to perceptual facilitation and that facilitation was not restricted to letters but could be generalized to nonletter stimuli. Experiments 3 and 4 showed that the location distribution of targets could be acquired for 2 global configurations concurrently and that facilitation referred to locations within the configurations, not to screen locations. The results indicate a general sensitivity of the visual system for the location of details in global configurations.

Visual stimuli are not randomly distributed. Generally, they are topographically ordered (i.e., they appear in stable spatial relations to each other), thereby forming distinct visual configurations. Two eyes, a nose, and a mouth form the familiar pattern of a face. Two wheels, a frame, a handlebar, and a saddle establish the configuration of a bicycle, and in a bathroom one can expect a mirror and a watertap to be above a basin. It is certainly reasonable to state that nearly all common objects and scenes are distinguished by stable spatial relations of their constituting parts (cf. Tversky & Hemenway, 1984).

Research in object and pattern recognition has provided ample evidence that the human visual system adapts to this ubiquitous presence of invariant spatial relations. The identification of objects is facilitated when they appear together with other objects in a familiar spatial arrangement (Biederman, 1972; Biederman, Mezzanotte, & Rabinowitz, 1982; Boyce, Pollatsek, & Rayner, 1989). For example, a buoy can be more readily identified if it is embedded in the scene of a harbor. However, facilitation vanishes if the objects that constitute the scene are arranged in an unusual manner or if they are arranged properly but the target object is placed in an untypical location (Antes, Penland, & Metzger, 1981; Biederman, 1972; Biederman, Glass, & Stacy, 1973; Hoffmann & Klein, 1988). Thus, the familiar topography of a scene facilitates the recognition of its respective parts, but facilitation is restricted to the locations where these parts are usually perceived.

Comparable effects have been reported for letters of the alphabet. A briefly presented letter is more readily identified

if it is properly embedded in a familiar word than if it is presented on its own (the *word-superiority effect*; Reicher, 1969; Wheeler, 1970). Again, the facilitation vanishes if the letters of the word are mixed up in an anagram (Baron & Thurston, 1973; Wheeler, 1970). Apparently, the perception of a letter profits from its correct embedding in a familiar word in the same way as does the perception of an object from its embedding in a familiar scene.

These findings allow the following tentative conclusions: First, the visual system seems to be able to extract the prototypical spatial relations between parts of visual configurations. Second, the visual system seems to accumulate the frequencies of parts in different locations. Third, this acquired information seems to facilitate the processing of stimuli that appear in their typical place (i.e., a place where they are probable). Thus, an object is more readily identified if it appears in its usual location within a scene, and a letter is more readily identified if it appears in its usual position within a word.

The outlined considerations have more or less explicitly influenced recent theories of object and word recognition. According to the recognition-by-components theory by Biederman (Biederman, 1987; Hummel & Biederman, 1992), a visual configuration is first parsed into a set of simple geometric components (the so-called "geons"). The spatial arrangement of these geons is then determined. In a final step, the gained structural pattern is compared with a set of stored object models. The perceived configuration is assigned to the model having the highest similarity with the identified geons and their spatial relations. Hence, object identification is based on comparing the topography of identified geons with corresponding object models in memory.

Examining topographical information about object details is also part of a model by Kosslyn, Flynn, Amsterdam, and Wang (1990). They assumed that object identification starts with the examination of global object properties. If the global appearance of a configuration allows only a tentative identification, an attention window is shifted to selected locations. At the same time, representations of the to-be-expected details in these locations are activated. If the

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expected details are present, they are readily recognized and the configuration is identified as the presumed object. If the expected details are not present, an alternative conjecture is set up and tested (for a similar view, see Hoffmann, 1995). Thus, a process is again proposed that presumes knowledge about the location of details within object configurations, leading to a facilitated recognition of the details in their expected locations.

Finally, models of word recognition also assume that knowledge about the location of letters within words is stored. For example, in the interactive activation model by McClelland and Rumelhart (1981), word knowledge is represented in a hierarchical network. On the bottom level, the nodes correspond to letter features. On the middle level they correspond to letters and to words on the highest level. For each word node, there are as many subordinated letter nodes as there are positions within the word. The node for each position represents the identity of the corresponding letter at that particular location. Consequently, the activation of a word node leads to an activation of its subordinated letter nodes and in turn to an increased perceptual sensitivity for those letters that are to be expected in the respective locations. In terms of this model, the word-superiority effect is based on the assumption that the perception of a word leads the visual system to expect the letters at their corresponding positions.

To summarize, experimental findings, as well as theoretical considerations, lead to the conclusion that the perception of familiar configurations includes expectancies about the proper location of details, so that the recognition of those details in their appropriate location is facilitated. Although these general considerations are widely accepted, there is little research that has explicitly examined the effects of detail expectancies and their determining factors (cf. Neisser, 1976). The present research was conducted to overcome this deficit. However, before introducing our specific purposes, we review in more detail the three studies that inspired the current experiments.

In the first study, carried out by Kinchla (1977), participants were briefly (10 ms) presented with two global letters (L and T), each consisting of six local letters. Participants had to decide whether a local letter F was present. The experimental variation concerned the frequency of the target letter within the two global letters. The target was presented twice as often in one global letter than in the other (50% vs. 25%). As the result, the rate of target-present responses was more affected by the presence or absence of the target in the global letter where it was presented more often, suggesting that participants focused their search for the target on that global letter.

Kinchla's (1977) results indicate a sensitivity of the visual system for the frequencies of details in global configurations. However, they do not yet provide any hint of whether there is also a sensitivity for the probable location of the local target within the global letter. That the visual system in fact acquires information about the location of details can be concluded from experiments by Lambert and Hockey (1986). In their experiments, a diamond- or elliptical-shaped stimulus was presented on the left or right of a central fixation

point. Participants had to decide whether the stimuli were vertically or horizontally oriented. Each stimulus was preceded by a location cue that was valid in 80% of the trials. Additionally, the presentation frequencies of the two shapes (diamonds and ellipses) varied in the two locations. For example, on the right side a diamond was presented in 80% of the trials, whereas on the left an ellipse was presented in 80%. Thus, on each side, one of the shapes was presented four times as often as the other. Lambert and Hockey found that participants responded faster to stimuli that appeared in cued locations. This corresponds to the notion of an attentional shift to that location (Posner, Nissen, & Ogden, 1978; Posner, Snyder, & Davidson, 1980). Additionally, there was a pronounced effect of stimulus frequency. Regardless of the location cue, in each location the shape that was presented more frequently was processed faster. In the above example, diamonds were processed faster than ellipses on the right side, and ellipses were processed faster than diamonds on the left side (cf. Kingstone & Klein, 1991).

These results indicate that information about the frequency of stimuli in both locations was accumulated. Furthermore, directing attention to a location seemed to be associated with participants expecting to see the stimulus that was perceived most often in that place. In this sense, location-specific stimulus expectancies come into play. However, in these experiments, participants' attention was always directed by a cue, and they were explicitly informed about the stimulus frequencies in the two locations. Therefore, it is questionable whether location-specific stimulus expectancies would also be established without any explicit attentional cue and without any information about stimulus distribution. Furthermore, stimuli were not embedded into a global configuration, so that it is unknown whether the stimulus expectancies can also refer to relative locations of global patterns.

Miller (1988) reported data on these issues. In one of his experiments (Experiment 2), participants had to decide whether one of two target letters was present in a four-letter string. Both targets were presented equally often but occurred with different frequencies in the four locations. One target (test target) was equally distributed (e.g., 10, 10, 10, and 10 in a block of 160 trials), whereas the other (inducing) target occurred particularly often in one location and rarely in any other position (e.g., 2, 34, 2, and 2). The results showed that both targets were detected fastest in the location where targets were presented the most often (Position 2 in the above example, with  $10 + 34 = 44$  presentations). This corresponds to the probability effect in visual search reported by Shaw and Shaw (1977). Recognition performance was better in locations with a high probability of containing a target. There was also an interaction with type of target. The probability effect was more pronounced for the inducing target than for the test target. A closer look indicates a crossover interaction that fits in appropriately with the experiments of Lambert and Hockey (1986). In the favored location, the inducing target was detected faster than the test target (802 vs. 818 ms), whereas this pattern was reversed in the other locations (902 ms for the inducing target and 865 ms for the test target); that is, in each respective location, the

target that was detected faster had been presented there more often. The effect occurred even though participants did not receive location cues or information about the locational distribution of the targets. Thus, participants seemed to spontaneously develop separate target expectancies for the string locations according to the experienced target frequencies.

The conclusion that target expectancies were actually acquired for string locations remained doubtful as long as the placement of the string on the screen was kept constant, so that string locations were confounded with screen locations. To disentangle the effect of string and screen locations, Miller (1988, Experiments 1 and 3) varied the placement of the strings on the screen. After extensive training, the strings were occasionally shifted one position to the left or to the right, so that the favored string position of the inducing target fell on a new screen location and a new string position fell on the formerly favored screen location. The results indicated that target recognition was facilitated at the trained screen location as well as at the trained string location.

Miller (1988) accounted for the results by assuming two different mechanisms working in concert: a spatially directed spotlight and a network of position-specific letter detectors (PSLDs). The spotlight was thought to be responsible for the facilitation of target detection in those screen locations where targets frequently appeared. This effect is assumed to be target unspecific (i.e., any target in the corresponding screen location profits from the spot). Conversely, PSLDs are assumed to provide target-specific effects in string locations. Miller defined PSLDs as "units for detecting the presence of a particular letter identity in a particular position within a letter string" (p. 468). Therefore, he assumed, as did McClelland and Rumelhart (1981) in their word recognition model, that for each string location, letter detectors develop that can be more easily activated the more often the corresponding letter has been perceived there. As a consequence, the inducing target is detected more readily in the favored string location where it was presented more often, and the test target is more easily detected in the remaining string locations because it was more frequent there.

To our knowledge, Miller's (1988) research is the only series of experiments that explicitly demonstrated a sensitivity for the frequencies of details in certain locations within global configurations. The reported effects were obtained with letters in linear strings, and Miller accounted for the effects by a mechanism that he assumed to be reserved for the registration of letter distributions in words. For example, Miller (1988) hypothesized that "the responses of PSLDs may decrease with increasing separation between letters, because the perception of a unified string may disappear" (p. 469); that is, Miller assumed that PSLDs are in fact restricted to letter strings. However, as we argued in the introduction, the acquisition of detail expectancies for configurational locations should be a more general mechanism using redundancies in the distribution of any kind of visual stimuli in any kind of global configuration.

There is a second point that limits the generalizability of Miller's (1988) findings: His participants adapted to the

letter distribution in only one single string (i.e., a string of constant length). In natural settings, humans shift gaze from object to object, so that information about the distribution of details for multiple objects must be acquired concurrently. Thus, to claim a general mechanism for the development of location-specific stimulus expectancies, not only independence from wordlike stimuli but also the ability to concurrently acquire information about the distribution of details within different configurations needs to be shown.

The present experiments were designed to contribute to both issues. First, we explored whether location-specific stimulus expectancies would also develop for letters in word-dissimilar configurations and for nonletter stimuli. Second, we explored whether participants would be able to concurrently adapt to the distributions of local stimuli within two different global configurations. As under natural settings, location-specific stimulus expectancies will be useful only if they refer to configuration-related locations, we further examined the question of whether the stimulus-specific expectancies would in fact be bound to relative locations within the different configurations or to screen locations.

## Experiment 1

The purpose of Experiment 1 was to examine whether a target-specific facilitation of recognition at specific locations could be observed when material that does not resemble words is used, making PSLDs ineffective. For this purpose, Miller's (1988) stimuli were modified in three ways: First, instead of four, seven letters were presented. Second, the letters were no longer presented as linear strings; rather, they were arranged to form either a "wave"-like or a "bird"-like global configuration, as can be seen in Figure 1. Finally, the interletter distance was increased from  $0.5^\circ$  to  $1.9^\circ$  of visual angle. If the target-specific facilitation of recognition at string locations reported by Miller is driven by PSLD mechanisms, which, by definition, are reserved for letter recognition in words, it should be significantly reduced or even absent with stimulus material that has no word similarity. On the other hand, if this effect were due to a more general mechanism, comparable effects should also appear with the configurations that were used here.

Besides the stimulus material, the task was also modified. Whereas in Miller's (1988) experiments participants had only to decide whether one of the two targets was present, in our experiment each target was assigned to a different response key. Participants were instructed to press the key that corresponded to the presented target as fast as possible without making errors. This procedural change should ensure that observers actually had to discriminate the targets and did not rely on their responses on joint target properties, which, of course, would undermine any target-specific effects. This task also allowed the removal of target-absent trials that were of minor interest in the present context because they did not provide information about target locations.

The experimental variation concerned the frequencies of the two targets in the respective locations within the bird and

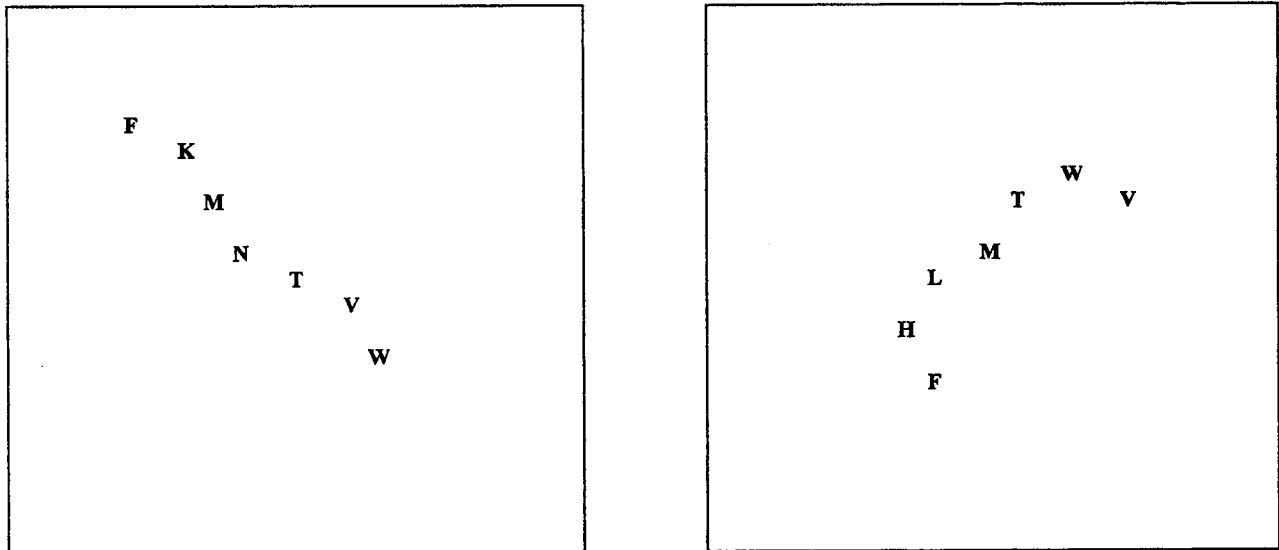


Figure 1. Example stimuli from Experiment 1. Left: The wave letter configuration. Right: The bird letter configuration.

wave configurations (see Table 1). As in Miller's (1988) experiments, one target was presented equally often in all locations, whereas the other target appeared particularly often in one of the seven locations (i.e., the critical location) and rarely in any other location. The main question was whether the recognition of individual targets in the various locations would be influenced by their frequency of occurrence despite the use of word-dissimilar letter configurations.

### Method

**Participants.** Twenty-four undergraduates (11 men, 13 women) at the University of Würzburg with normal or corrected-to-normal vision served as observers in fulfillment of a course requirement. Each student was tested in a single session lasting about 45 min.

**Apparatus and stimuli.** The presentation of the stimuli and the recording of responses and reaction times (RTs) were made by a 486 IBM-compatible PC with a 15-in. (38.1 cm) video graphics monitor. The stimuli were presented in an invisible  $21 \times 21$  matrix that was 20 cm wide and 18 cm high on the used display. In this matrix the letters were arranged as Figure 1 shows. Each of the configurations consisted of seven letters (six distractors and one target) that were presented simultaneously. The letters were 6 mm high and 4 mm wide and were separated by a center-to-center

distance of 2 cm. The viewing distance was approximately 60 cm, so the interletter distance amounted to approximately  $1.9^\circ$ . The characters were presented in blue on a white background. The Ctrl and Alt key of the standard PC keyboard were the response keys.

**Procedure.** Half the observers were presented with the bird configuration, and the other half received the wave configuration. Targets were the letters H and K, and the distractors were the letters F, L, M, N, T, V, and W. The assignment of the status "inducing target" and the assignment of the response keys to the two target letters were counterbalanced in each configuration group. For each observer, there was one critical location. For the bird configuration, the Locations 3, 5, and 7, and for the wave configuration the Locations 2, 4, and 6 (in left-to-right order, respectively) served as the critical location for 4 observers each. Each session had five blocks of 100 trials. An example of a frequency distribution of the inducing and test target can be seen in Table 1.

Each trial began with a 4400-Hz warning tone of a 125-ms duration. The stimulus display was presented 600 ms after the offset of the tone and remained visible until the response was made. Speed and accuracy feedback was then presented for 1 s. The offset of the feedback was the onset of the warning tone for the next trial.

Observers were instructed that they would be presented with a set of seven letters and were told to search for the two possible target letters among them. They were also told that one target was always present. Observers were asked to respond with the corresponding key as quickly as possible without making errors. The keys were pressed with the index fingers of the left and right hand. No information about the location distribution of the targets was given.

Table 1  
Probability of the Test Target and the Inducing Target in the Seven Locations of Experiment 1

Target	Location							Total (%)
	1	2	3	4	5	6	7	
Test	7	7	7	7	8	7	7	50
Inducing	2	2	38	2	2	2	2	50
Total (%)	9	9	45	9	10	9	9	100

### Results

RTs below 100 ms and above 2,500 ms were considered as outliers and excluded. This procedure removed 0.50% of the RTs. The data on the critical location, the locations directly adjacent to the critical one, and all the other (remote) locations were pooled together, resulting in three types of locations (critical, adjacent, and remote) respectively. The

mean RTs for correct responses and percentage of errors (PEs) were computed for each observer, location type, and target type.

Mean RTs for correct responses and PEs were entered into separate mixed analyses of variance (ANOVAs) with location (critical, adjacent, and remote) and target type (inducing, test target) as within-subjects variables and configuration (bird and wave) as a between-subjects variable. The RT analysis revealed a main effect of location,  $F(2, 44) = 89.85$ ,  $p < .001$ ,  $MSE = 7,949.9$ . The location effect was somewhat more pronounced in the wave figure than in the bird figure, leading to a small interaction between figure and location,  $F(2, 44) = 4.35$ ,  $p < .05$ ,  $MSE = 7,949.9$ . Presumably, this was the result of the more elongated wave, leading to slower responses in the most remote locations in this configuration. Because this effect was not found in Experiments 2 and 3, in which the same configurations were used, it is not discussed further. A highly reliable interaction between target type and location was also found,  $F(2, 44) = 11.65$ ,  $p < .001$ ,  $MSE = 3,765.7$  (see Figure 2). Single contrasts showed that the inducing target was detected faster than the test target in the critical location,  $F(1, 22) = 5.33$ ,  $p < .05$ ,  $MSE = 6,570.1$ , whereas the test target was recognized faster than the inducing target in remote locations,  $F(1, 22) = 5.60$ ,  $p < .05$ ,  $MSE = 9,318.7$ .

The mean error rates for the test target in the critical, adjacent, and remote locations were 6.1%, 6.3%, and 4.4%, respectively, and 3.6%, 7.9%, and 12.8% for the inducing target, respectively. The ANOVA of the error data yielded a main effect of location,  $F(2, 44) = 12.30$ ,  $p < .001$ ,  $MSE = 13.7$ , and target type,  $F(1, 22) = 11.78$ ,  $p < .01$ ,  $MSE = 18.9$ . The error rate was higher for the inducing target. This effect was caused mainly by a tendency to confuse the inducing target with the test target in the remote locations. As for RTs, the interaction between target type and location became significant,  $F(2, 44) = 11.22$ ,  $p < .001$ ,  $MSE = 32.1$ . Single contrasts showed that responses to the inducing target were more accurate than to the test target in the critical locations,  $F(1, 22) = 5.0$ ,  $p < .05$ ,  $MSE = 14.5$ , whereas the test target was recognized more accurately than the inducing target in the remote locations,  $F(1, 22) = 21.29$ ,  $p < .001$ ,  $MSE = 35.5$ . No other effect approached significance.

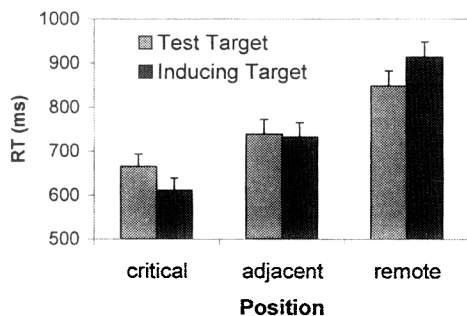


Figure 2. Mean reaction times (RTs) as a function of location type and target type with 95% confidence intervals in Experiment 1.

## Discussion

The purpose of Experiment 1 was to replicate the location-specific target probability effect in visual search (i.e., relatively faster detection of a probable than an improbable target in a certain location) originally reported by Miller (1988). The replication was successful. As in Miller's research, targets in general were recognized fastest in the critical location with the highest overall target frequency. The recognition time increased with the distance to the critical location. More important, this effect interacted with the type of target: In the critical location, the more frequent inducing target was recognized faster than the test target, and in the remote locations, the test target was recognized faster than the inducing target. In the locations adjacent to the critical location, the targets were recognized about equally fast. The error data confirm this interaction: In the critical location, observers made more errors for the test target, whereas this pattern was reversed in the remote locations.

The general facilitation of both targets in the critical position suggests a mechanism that allocates unspecific visual resources to the location where targets appear particularly often. The spotlight theory of visual attention provides a sufficient explanation for this effect. However, it is plausible to assume that the location distribution of the targets may also have influenced overt scanning behavior; thus, the position effect may be partly the result of eye movements. However, as already pointed out by Miller (1988), neither overt nor covert orienting of visual attention can account for the target specificity of the effect. The interaction between location and target type suggests that the visual system has the capability to assign specific resources to locations for the processing of a particular target. Because this interaction could be observed with stimulus material having little (if any) word similarity, it seems impetuous to attribute this effect to special letter-recognition processes such as PSLDs. In contrast, it seems more appropriate to assume a more general capability of the visual system to acquire and apply knowledge about the distribution of details (local parts) in global patterns.

The present experiment gave us the opportunity to distinguish among three types of locations: critical, adjacent, and remote. This distinction could hardly have been applied by Miller (1988) using only four locations. The data reveal considerable differences within the noncritical locations (adjacent and remote) despite identical target frequencies. In particular, the advantage of the test target over the critical target in the remote locations disappeared in the adjacent locations. There are at least two possible accounts for this effect: First, it is possible that target expectancies are acquired for approximate areas including more than one location, what would correspond to the fact that locations of details in natural objects vary slightly from instance to instance. As a consequence, detection in the adjacent locations would be affected by target expectancies in both the critical and remote locations, leading to an intermediate data pattern. Second, the intermediate data pattern for adjacent locations is also consistent with the assumption that

observers acquire expectations only for the critical location where they expect to see the inducing target. If the inducing target is presented there, it is easily identified, and the corresponding response is executed readily. If the test target is presented, the expectancy for the inducing target must be canceled. This process is time-consuming and leads to errors. If neither target can be perceived in the critical location, the search is directed to other locations, accompanied by an expectancy for the test target that increases with the distance to the critical location. Our data were not sufficient to decide between these alternatives.

A closer comparison of the data with those of Miller (1988, Experiment 2) shows that in the present experiment, all effects were stronger. Whereas Miller found an average location probability effect of 74 ms, the RT difference between the critical and remote locations amounted to 242 ms in the present experiment. The advantage for the inducing target over the test target at the critical position was 16 ms in Miller's experiments and amounted to 54 ms in ours. Furthermore, the advantage of the test target over the inducing target at the remote positions increased from 37 to 66 ms. Several factors could be responsible for the strengthening of the effects. First, it is reasonable to assume that the increased interletter distance made the locations more distinguishable. Second, the assignment of different responses to the targets could have led to a stronger tendency to discriminate or even identify the target, as it was intended. Third, no target-absent trials were used, so information about target locations could be collected in every trial.

Most important, not only the recognition of a particular target but the corresponding response also could have been primed by the given target location. Therefore, the strengthening of the target-specific effects may not be the exclusive result of a facilitated target detection but of a facilitated response execution. The present data do not allow one to determine whether perceptual expectancies or expectancies for responses are responsible for the observed facilitation. This point certainly warrants further study. There was a second problem with Experiment 1. Although no wordlike strings were used, the observers were still presented with letters. Therefore, it can be argued that the effects were still caused by PSLDs, assuming that PSLDs can adapt to nonlinear letter configurations. Experiment 2 was designed to deal with both issues.

## Experiment 2

Experiment 2 had two purposes. First, we needed to determine whether the interaction between location and target type observed in Experiment 1 was the result of expectancies for the respective manual responses the targets in Experiment 1 were associated with. For this purpose, we modified the response mode. The observers had to give the same response if either one of the two targets was present and another response if both targets were absent. Consequently, no target-specific response preparations could take effect. If the location-specific target probability effect observed in Experiment 1 reflects target-specific response expectancies, it should not be observable in Experiment 2.

If, on the other hand, the effect is located in the perceptual system, the modification of the response mapping should be of minor influence.

The second purpose of Experiment 2 was to further examine whether the facilitated processing for location-typical targets would also be observed with nonletter stimuli. For this purpose, we used geometrical line patterns instead of letters as local stimuli. This, by definition, rules out the influence of special processes confined to the recognition of letters.

## Method

*Participants.* Twenty-four different undergraduates (13 women, 11 men) at the University of Würzburg with normal or corrected-to-normal vision served as observers in fulfillment of a course requirement. Each student was tested in a single session lasting about 45 min.

*Apparatus and stimuli.* The apparatus was the same as that used in Experiment 1. Half the observers received letters as stimuli. For these observers, the letters F and K served as targets and the letters E, M, N, T, V, W, and X were used as distractors. For the other half, the ASCII characters  $\#$  and  $\text{lf}$  were used as targets and the characters  $\ddagger$ ,  $\text{ll}$ ,  $\text{ll}$ ,  $\text{ll}$ ,  $\text{ll}$ ,  $\text{ll}$ , and  $\text{ll}$  served as distractors. Within each of the two groups, half the observers were presented the bird configuration, and the other half received the wave configuration. The same critical positions were used as in Experiment 1.

*Procedure.* The observers had to decide whether one of the two possible targets was presented. The observers were informed that only one or neither target would be presented. A target was present in 66% of the trials. All observers pressed the right key when a target was present and the left key when targets were absent. The frequencies of the inducing target and the test target within the target-present trials were the same as in Experiment 1 (see Table 1). The experiment was run in four blocks of 150 trials each.

## Results

RTs below 100 ms and above 2,500 ms were discarded as outliers (1.8% of all responses, 4% of the target-absent trials, and 0.6% of the target-present trials).

*Target-absent trials.* The mean RTs and error rates were 1,294 ms (10.7%) for the observers with letter stimuli and 1,628 ms (9.9%) for those with line patterns as stimuli.

*Target-present trials.* The RTs from correct responses were entered into a four-way ANOVA with stimulus material (letter vs. geometrical patterns) and configuration (bird vs. wave) as between-subjects variables and target type (inducing vs. test) and position (critical, adjacent, and remote) as within-subjects variables (see Figure 3). The search times overall were faster with letters,  $F(1, 20) = 6.55$ ,  $p < .05$ ,  $MSE = 101,801.8$ . As in Experiment 1, the effect of position was significant,  $F(2, 40) = 158.66$ ,  $p < .001$ ,  $MSE = 9,695.0$ . The observers detected targets the fastest in the critical location and more slowly the more distant a target appeared. The position effect was more pronounced with the geometrical patterns,  $F(2, 40) = 5.98$ ,  $p < .01$ ,  $MSE = 9,695.0$ . The interaction between position and target type found in Experiment 1 was again highly reliable,  $F(2, 40) = 8.45$ ,  $p < .001$ ,  $MSE = 4,422.6$ . Single contrasts showed

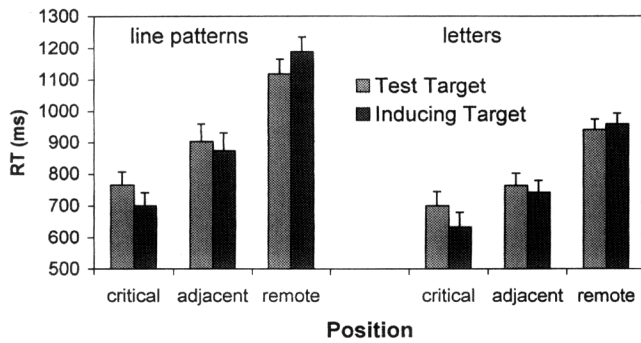


Figure 3. Mean reaction times (RTs) as a function of stimulus type, location, and target type with 95% confidence intervals in Experiment 2.

that in the critical location the critical target was detected faster than the test target,  $F(1, 23) = 5.94, p < .05, MSE = 8,736.5$ , whereas in the remote locations the test target was (nearly significantly) detected faster than the critical target,  $F(1, 23) = 3.79, p < .07, MSE = 6,305$ . No other effect approached significance. In particular, the interaction of position and target type was not modified by the type of stimulus material,  $F(2, 40) = 0.71, p > .4, MSE = 4,422.6$ , for the three-way interaction among stimulus material, position, and target type.

The mean error rates with geometrical line patterns as stimuli in the critical, adjacent, and remote locations were 7.3%, 9.9%, and 12.3%, respectively, for the test target and 5.0%, 10.8%, and 17.8%, respectively, for the inducing target. With letters the corresponding error rates were 3.8%, 12.8%, and 15.3% for the test target and 3.6%, 8.8%, and 20.0% for the inducing target. The analysis of the error data replicated the effect of position,  $F(2, 40) = 23.31, p < .001, MSE = 67.37$ , and the interaction between position and target type,  $F(2, 40) = 5.56, p < .01, MSE = 28.16$ . No other effect or interaction approached significance.

### Discussion

In Experiment 2 we intended to rule out two alternative interpretations of the data from Experiment 1. First, to exclude any potential influence of target-specific response preparation effects, observers had to press a single key for both targets in Experiment 2. Despite this modification the same data pattern emerged (see Figure 3). Thus, it is highly improbable that response preparation had any substantial influence on the current task. Therefore, the interaction between location and target type is presumably a result of processing facilitations in the perceptual system. Whether this facilitation is mediated by an increased sensitivity or by a lowered recognition threshold for the expected target still remains open. For clarification, experiments are needed that allow an evaluation of detection performance in different locations by measures of signal-detection theory.

A second problem with Experiment 1 concerned the used stimulus material. Because letters were again presented, it could not be ruled out that still letter detectors were

responsible for the observed effects, although the letters were not arranged as wordlike strings. To deal with this matter, we also used geometrical line patterns as stimuli along with letters. The used line patterns were sufficiently letter dissimilar to expect a substantial decrease (if not removal) in the interaction between location and target type, if the interaction in fact would be restricted to letter detectors. Clearly, this was not the case. Besides a general increase in RTs, the geometrical line patterns led to the same data pattern as the letters, indicating that location-specific target expectancies can be established for nonletters and presumably for any kind of stimuli.

To summarize, the results of Experiments 1 and 2 support the notion that the visual system accumulates information about the locations in which certain stimuli appear within global configurations, so that expectancies about the most probable location of these stimuli are established, leading to a facilitated recognition of local details in their expected locations. However, we have to concede that the present experimental settings were still too simple to justify such a general notion. Each observer was presented with only one configuration in only one place on the screen. In natural settings, however, the visual system is confronted with percepts of numerous objects in varying configuration from varying viewpoints. To convincingly claim that even under such complex conditions the visual system accumulates information about the location of local details in global configurations, location-specific target expectancy effects have to be demonstrated under more complex conditions. Experiments 3 and 4 were conducted to take a first step in this direction.

### Experiment 3

Experiment 3 was mainly conducted to examine whether observers would be able to acquire location-specific target expectancies for two different configurations concurrently. For this purpose, both configurations of the preceding experiments (wave and bird) were randomly presented in one of two different areas on the screen. As in Experiment 1, observers had to discriminate between two target letters. Again, in each of the configurations one target (the test target) appeared equally often in all locations, whereas the other (inducing) target occurred particularly often in one critical location. Inducing and test targets were counterbalanced between the configurations (i.e., the inducing target in the wave was the test target in the bird and vice versa). Thus, observers faced a situation in which they had to search for two targets in two different configurations with both targets differently distributed. If observers are able to concurrently adapt to the target distributions in both configurations, the interaction between location and target type should be present as in Experiments 1 and 2 regardless of the configuration presented.

The use of two configurations also allowed us to examine whether target expectations would be bound to screen locations or, as assumed, to the relative locations within each configuration. To decide which of the two reference systems would be used, we placed the configurations so that the

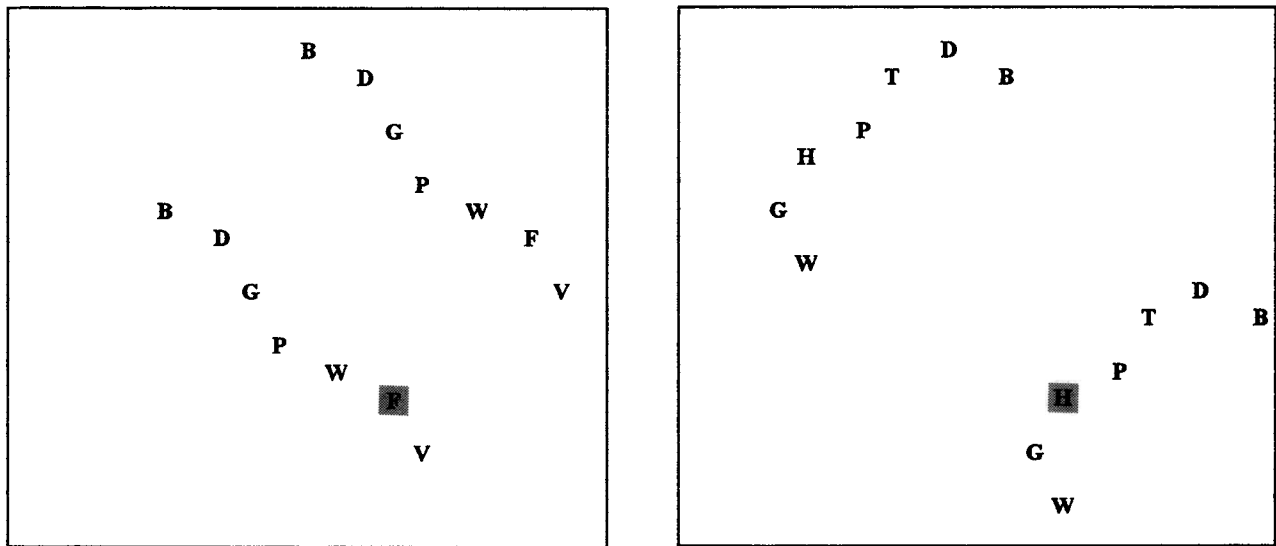


Figure 4. Positioning of the letter configurations on the screen in Experiment 3. Only one configuration was presented in each trial. The overlapping critical locations are shaded.

critical locations of the two bottom configurations fell on the same screen location, whereas the critical locations of the two upper configurations fell on different screen locations (see Figure 4). As a consequence, targets were presented twice as often in the overlapping critical locations as in the nonoverlapping critical locations, and, more important, both target letters were presented in the overlapping locations equally as often (see Table 2). Consequently, if expectancies are related to screen locations, target recognition should be faster in the overlapping locations than in nonoverlapping locations because targets appeared twice as often there. Furthermore, in the overlapping locations, no advantage for the inducing targets should be observed because both targets appeared equally often there. If, on the other hand, target expectancies are related to configural locations, no difference between overlapping and nonoverlapping locations should occur because it should not matter where on the screen, only where within the configurations, the target appears.

### Method

**Participants.** Sixteen undergraduates (13 women, 3 men) served as observers in a single 1-hr session.

Table 2  
Relative Frequency (in % of Trials) of Each Target Letter in the Overlapping Critical Locations in Experiment 3

Configuration and target	Overlapping critical location
Bird	
H (test)	1.75
F (inducing)	9.50
Wave	
H (inducing)	9.50
F (test)	1.75

**Apparatus.** The apparatus was the same as in Experiment 1.

**Stimuli and procedure.** In each trial one of the two letter configurations (bird and wave) at one of its two screen positions, as illustrated in Figure 4, was presented to the observers in a random order and equally as often. Targets were the letters F and H and the distractors were the letters B, D, G, K, P, T, and W. The location distribution of the two target types was the same as in Experiment 1, except for the fact that Position 6 in the wave configuration and Position 3 in the bird configuration served as the critical location for all observers. The inducing target of the bird was the test target in the wave and vice versa. For half the observers, the H was the inducing target in the bird; for the other half it was the F. Half the observers responded to the F with the left hand and to the H with the right hand. For the other observers, the mapping was reversed. The experiment was run in three blocks of 200 trials.

### Results

The outlier elimination removed 1.21% of the data. The mean RTs of the correct responses and PEs were entered into separate ANOVAs with figure (bird-bottom, bird-top, wave-bottom, and wave-top), location (critical, adjacent, and remote), and target type (inducing, test) as within-subjects variables. The RT analysis revealed a main effect of location,  $F(2, 30) = 37.54, p < .001, MSE = 27,050.9$ . As in Experiment 1, the interaction between location and target type became highly reliable,  $F(2, 30) = 10.35, p < .001, MSE = 8,820.8$  (see Figure 5). Single contrasts revealed faster responses for the inducing target than for the test target in the critical locations,  $F(1, 15) = 14.35, p < .01, MSE = 5,277.8$ , and faster responses for the test target than for the inducing target in the remote locations,  $F(1, 15) = 13.80, p < .01, MSE = 6,057.7$ . No other effect approached significance.

The mean error rates in the critical, adjacent, and remote locations for the test target were 6.2%, 6.9%, and 5.1%, respectively. The corresponding error rates for the inducing



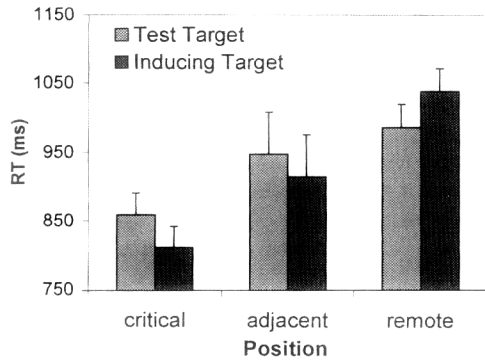


Figure 5. Mean reaction times (RTs) as a function of location type and target type with 95% confidence intervals in Experiment 3.

target were 4.1%, 4.8%, and 7.6%, respectively. In the error analysis only the interaction between location and target type reached significance,  $F(2, 30) = 4.00, p < .05, MSE = 57.6$ . Single contrasts showed no significant difference between the targets in the critical locations,  $F(1, 15) = 1.91, p > .10, MSE = 72.7$ , and only a marginal difference in the remote locations,  $F(1, 15) = 3.22, p < .10, MSE = 63.6$ .

A separate ANOVA for the critical locations with the variables of target type (inducing vs. test target) and overlap (nonoverlapping vs. overlapping) led to a significant effect of target type,  $F(1, 15) = 14.34, p < .01, MSE = 2,636.4$ . Responses to inducing targets were faster than to test targets (see Figure 6). More important, this advantage did not differ between the overlapping and nonoverlapping critical locations,  $F(1, 15) = 0.66, p > .4, MSE = 4,294.6$ , for the interaction between overlap and target type. The advantage for the inducing target approached significance in overlapping critical locations on its own,  $F(1, 15) = 3.64, p < .08, MSE = 2,737.1$ . The overlapping and nonoverlapping critical locations did not differ,  $F(1, 15) = 0.13, p > .90, MSE = 6,191.1$ . The mean error rates for the test targets were 4.9% in the nonoverlapping critical positions and 7.7% in the overlapping critical positions. The corresponding error rates for the inducing targets were 4.4% in the

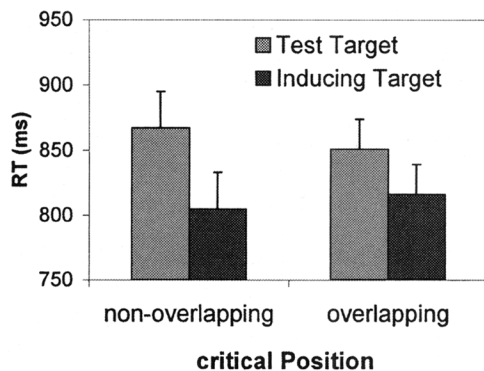


Figure 6. Mean reaction times (RTs) in the critical locations as a function of overlap and target type with 95% confidence intervals in Experiment 3.

nonoverlapping and 3.8% in the overlapping locations. The analysis for the error data showed no reliable effects.

### Discussion

The present experiment had two purposes: First, we wanted to examine whether observers would be able to concurrently establish different target expectancies within different configurations. For this reason two targets were differently distributed among the locations of two different configurations, presented at different screen positions. Despite the increased complexity of the experimental settings, the same data pattern as in the preceding experiments was found (i.e., the location effect and the interaction between locations and target types occurred independently of the configurations and their position on the screen). Obviously, observers easily adapted different target expectations to the locations of two configurations concurrently.

The second purpose was to verify whether target expectancies would refer to configural locations or to screen locations. For this reason, the configurations were placed on the screen so that their critical locations either did or did not overlap at a common screen location. If target expectancies refer to screen locations, targets should be detected faster in overlapping locations because targets were presented twice as often there than in the nonoverlapping locations. This was not the case. Second, the effect of the target type should vanish in overlapping screen locations because both targets were equally often presented there. Again, there was no indication for this effect, as the data revealed no interaction between target type and overlap. The respective inducing target was recognized faster than the respective test target in the nonoverlapping and overlapping critical locations. Both results speak in favor of the notion that the target expectancies refer to at least primarily to configural locations.

The preceding line of reasoning is based on the absence of significant effects. Such a conclusion must be viewed with caution. The failure to reach significance may result from insufficient power of the present data analysis (cf. Cohen, 1988). Moreover, Figure 6 reveals that, at least on a descriptive level, there was still a small influence of screen positions, as the advantage for the inducing target decreased slightly in overlapping critical locations. To further explore this question, we conducted another experiment in which we increased the effort for the localization of targets within the configurations, which may result in a stronger impact of a screen-related frame of reference on the formation of target expectancies.

### Experiment 4

Objects not only appear at different places but also in different orientations. Varying object orientations may render the localization of parts more difficult depending on whether these locations are defined by orientation-bound or orientation-free relations (Takano, 1989). In a face, for example, the nose is located in the middle of and the chin is located at the bottom of the face. To determine where the nose is located, the orientation of the face is irrelevant, as

“in the midst of” is an orientation-free relation. However, to localize the chin, one has to determine where on a given face the top and the bottom are located, as “at the bottom” is an orientation-bound relation.

To introduce this complication in defining configurational locations, we arranged nine local letters on the screen to form the global digit “1” or the global digit “2.” Both digits were not only located at different screen locations but also in two possible orientations: upright and rotated by 90°. Figure 7 shows the positioning of the digits on the screen and the critical locations in each digit. In the digit “1” the upper peak and in the digit “2” the lower corner were chosen as critical locations (i.e., both critical locations were defined by orientation-bound relations). Consequently, not only the identity of the digit but also its orientation had to be considered to determine that configural location, where targets overall and especially the respective inducing targets were presented most often. The question was whether, under these more complicated conditions, target expectancies would still refer to configural instead of screen locations. All other aspects of the experiment were the same as in Experiment 3. The frequencies of the inducing and test target are displayed in Table 3. The assignment of target letters to target types was again counterbalanced between configurations, so that the inducing target in the one configuration was the test target in the other and vice versa.

As Figure 7 shows, the global digits again were placed so that their critical locations partly fell on the same and partly fell on different screen locations. Targets were presented twice as often in overlapping as in the corresponding nonoverlapping locations, and in the overlapping locations the respective frequency differences between inducing and test target disappeared (see Table 4). As in Experiment 3, this should allow us to determine the frame of reference where the target locations were defined.

Table 3  
Probability of the Test Target and the Inducing Target in the Nine Locations of the Configuration “1” in Experiment 4

Target	Location									Total (%)
	1	2	3	4	5	6	7	8	9	
Test	4	6	6	6	6	6	6	6	4	50
Inducing	2	2	34	2	2	2	2	2	2	50
Total (%)	6	8	40	8	8	8	8	8	6	100

Method

*Participants.* Sixteen different undergraduates (13 women, 3 men) served as observers.

*Apparatus.* The apparatus was the same as in Experiments 1, 2, and 3.

*Stimuli and procedure.* The targets were the letters F and H and the distractors were the letters B, E, G, K, P, S, T, W, and Z. The letter configurations are displayed in Figure 7. The critical locations were the peak position in configuration “1” and the lower corner in configuration “2.” The location frequencies of the inducing and test target can be seen in Table 3. The global configurations were placed on the screen so that the critical locations of the two top configurations overlapped. As in Experiment 3, the inducing target in one configuration was the test target in the other. Again, for half the observers, the F was inducing in the digit “1,” and for the other half it was the H. Half the observers responded with the left hand to the target F, and the other half responded with the right hand. Observers performed three blocks of 200 trials each.

Results

The same outlier criteria as in the foregoing experiments were applied here, resulting in the elimination of 1.35% of

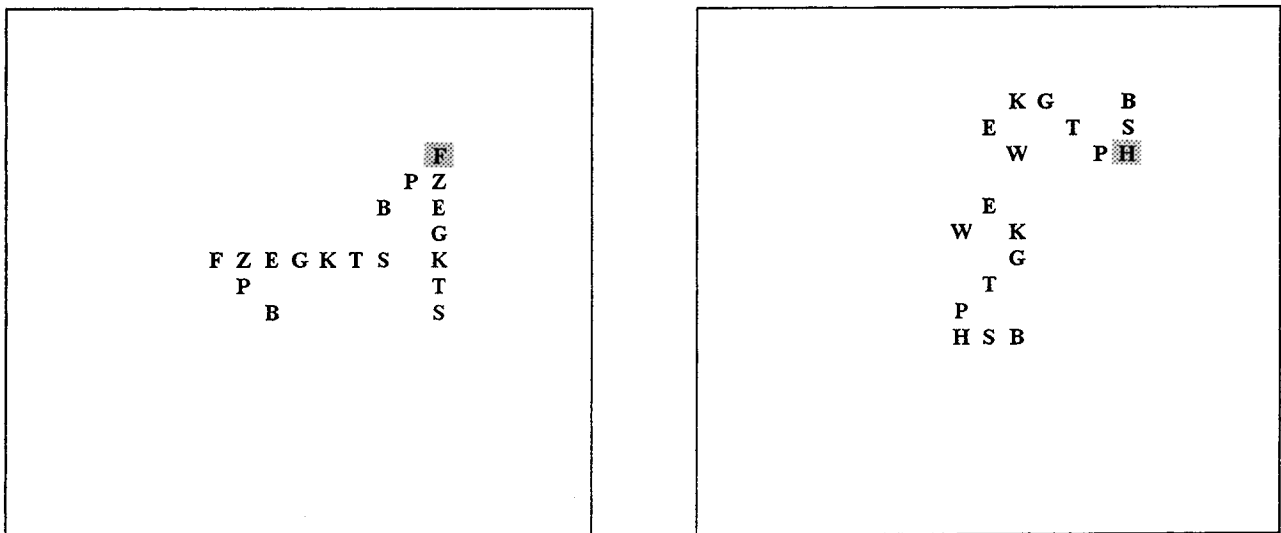


Figure 7. Positioning of the letter configurations on the screen in Experiment 4. Only one configuration was presented in each trial. The overlapping critical locations are shaded.

Table 4  
Probability of the Two Target Letters at the Overlapping Critical Locations in Experiment 4

Configuration and target	Overlapping critical location (%)
"1"	
H (test)	1.50
F (inducing)	8.50
"2"	
H (inducing)	8.50
F (test)	1.50

the data. The mean RTs of the remaining correct responses and PEs were entered into separate ANOVAs with figure and orientation (1 and 0°, 1 and 90°, 2 and 0°, and 2 and 90°), location (critical, adjacent, and remote), and target type (inducing vs. test) as within-subjects variables. As in the previous experiments, the factor location was highly reliable,  $F(2, 30) = 17.48, p < .001, MSE = 13,111.8$  (see Table 5). Additionally, there was a small effect of figure and orientation,  $F(3, 45) = 3.15, p < .05, MSE = 15,502.8$ , that was caused by faster responses in both figures "1" than in the two figures "2". The effect of location was also stronger in figures "1" than in figures "2" and resulted in a Figure and Orientation  $\times$  Location interaction,  $F(6, 90) = 12.93, p < .001, MSE = 18,345.8$ . This is presumably an effect of the closer relation between physical distance and positional distance in the nearly linearly structured figures "1" than in the curved figures "2". As in Experiments 1–3, the interaction between location and target type was highly significant,  $F(2, 30) = 10.12, p < .001, MSE = 10,538.3$ . Single contrasts revealed the familiar pattern of faster responses to inducing targets than to test targets in the critical locations,  $F(1, 15) = 14.27, p < .01, MSE = 11,955.1$ , and the reverse pattern in remote locations,  $F(1, 15) = 9.09, p < .01, MSE = 6,263.3$ . The interaction between location and target type varied slightly between the figures,  $F(6, 90) = 2.29, p < .05, MSE = 12,599.6$ , for the Target Type  $\times$  Location  $\times$  Figure interaction. It was somewhat more pronounced in figures "1" than in figures "2".

The mean error rates in the critical, adjacent, and remote locations for the test target were 3.4%, 4.8%, and 4.2%, respectively. The corresponding error rates for the inducing target were 3.0%, 2.9%, and 5.7%, respectively. The ANOVA of errors showed no reliable effects.

Table 5  
Mean Reaction Times (in Milliseconds) and Mean Error Rates (%) as a Function of Position and Target Type in Experiment 4

Target	Location					
	Critical		Adjacent		Remote	
	RT	ER	RT	ER	RT	ER
Test	954	3.4	964	4.8	980	4.2
Inducing	880	3.0	952	2.9	1,022	5.7

Note. RT = reaction time; ER = error rate.

To determine the reference system the participants used, we again computed a separate ANOVA for the overlapping–nonoverlapping critical locations with the variables of overlap and target type. The ANOVA for the critical locations revealed that observers detected inducing targets faster than test targets,  $F(1, 15) = 14.43, p < .01, MSE = 5,955$  (see Figure 8). This effect did not differ between overlapping and nonoverlapping locations,  $F(1, 15) = 1.56, p > .2, MSE = 1,593.7$ , for the interaction between overlap and target type. The advantage for the inducing targets also reached significance in the overlapping critical locations,  $F(1, 15) = 6.53, p < .05, MSE = 4,524.1$ . Targets were also detected faster at overlapping than at nonoverlapping locations,  $F(1, 15) = 4.84, p < .05, MSE = 8,435.8$ . The mean error rates in the nonoverlapping critical locations were 3.9% for the test target and 3.9% for the inducing target; in the overlapping critical locations, the error rates were 2.9% (test) and 2.1% (inducing). The ANOVA for errors yielded no significant effects.

### Discussion

The determination of configural locations was made more difficult in Experiment 4 than in Experiment 3 by presenting the configurations in varying orientations. In one configuration (the digit "1") the upper peak was the critical location, and in the other configuration (the digit "2") it was the lower corner. The determination of both locations presupposes the orientation of the respective configuration to be considered. The question was whether this additional effort would increase the impact of a screen-related reference system compared with Experiment 3.

The data replicate the general pattern of the first three experiments: A significant main effect of target location was found, as was a significant interaction between location and target type (see Table 5). In the critical and remote locations, the recognition of the inducing and test targets was facilitated. The persistence of the advantage for the inducing over the test target in the overlapping locations confirmed the

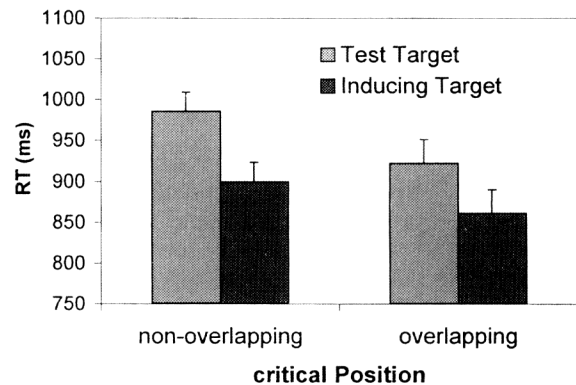


Figure 8. Mean reaction times (RTs) in the critical locations as a function of overlap and target type with 95% confidence intervals in Experiment 4.

preference of a configural reference frame in defining target locations.

However, there were also hints of a residual influence of a screen-related reference frame in the data (see Figure 8). The RT differences between the targets were, as in Experiment 3, slightly reduced in the overlapping locations (although the interaction between overlap and target type was far from being significant). This reduction corresponds with the fact that targets appeared equally often in this *screen* location. Furthermore, observers detected targets somewhat faster in the overlapping than in the nonoverlapping locations. This difference is consistent with the fact that targets appeared twice as often in overlapping locations.<sup>1</sup>

One reviewer of an earlier version of this article wondered whether the orientation of the configurations needed to be considered to determine configural locations. Observers could simply discriminate four distinct configurations, establishing target expectancies for each of them. In fact, this could be a reasonable strategy. Yet, this strategy can be applied to any misoriented pattern and thus is a problem with every orientation variation. For example, a square tilted for 45° clockwise can be seen as a diamond, or the upside-down letter *W* may be seen as an *M*, and so forth. Thus, every rotated object can also be seen as a distinct object. This, in fact, is the general problem of viewpoint independence the object identification system has to cope with. However, even if our observers would have discriminated four distinct configurations, it must be assumed that they used configuration-related reference systems to account for the data. Even more important, discriminating four instead of two configurations will certainly increase the effort in using configuration-related reference frames, which, of course, meets the main purpose of the orientation variation introduced in Experiment 4.

To summarize, the results of the present experiment confirm that the configurations were primarily used as a reference frame for the formation of target expectancies. Compared with Experiment 3, the increased effort to determine the configural target locations also led to a marginal influence of a screen-related reference frame. This suggests that in the formation of location-specific target expectancies, the efficiency of different frames of reference might be influenced by the effort caused by its application. We consider this point further in the General Discussion section.

### General Discussion

The present experiments were inspired by the assumption that the human visual system accumulates information concerning the location of visual stimuli, leading to expectancies for certain stimuli in certain locations. There are numerous indications for the effects of such expectancies, but their formation has rarely been experimentally explored. Research by Miller (1988) is an exception to the neglect of what we consider to be an important empirical phenomenon. Miller found that in a certain string position a specific target letter can be more readily detected the more often it has been presented there. This location-specific target probability effect was accounted for by PSLDs, which he assumed to

be more easily activated the more often the respective letter was observed in the respective location. The present experiments departed from this finding and theoretical consideration.

The first purpose of our experiments was to clarify whether the location-specific target probability effect would be restricted to letter strings, as Miller (1988) suggested, or whether it refers to a more general mechanism that uses redundancies in the locational distribution of any stimuli in any configuration. Second, we examined the ability of our observers to adapt to redundant target distributions in two configurations concurrently. Finally, we examined whether target expectancies do in fact refer to configural locations or whether other reference frames also come into play.

Experiment 1 provided evidence for the conclusion that the effects of a redundant distribution of target letters along the positions of a configuration of letters are not restricted to linear letter strings. Experiment 2 clearly confirmed the results of Experiment 1 with configurations of unfamiliar local line patterns instead of letter configurations. Both results suggest that location-specific target expectancies are not only established for letters within letter strings but also for configurations of nonletter stimuli and presumably for any stimuli in any configuration. Thus, not the kind of stimuli but their redundant spatial distribution seems to be crucial to cause the effect. We also found that location-specific expectancy effects were present when a unitary response instead of discriminative responses to the targets was required, suggesting that mainly perceptual, not motor, expectancies underlie the facilitated processing of location-typical targets.

Finally, the results of Experiment 3 and 4 show that redundancies in the distribution of targets in two configurations can be acquired concurrently. Regarding the spatial reference frames the target locations refer to, in Experiments 3 and 4 we also contrasted configurations against the screen as likely reference systems. The results indicate that observers primarily referred target expectancies to configural locations (i.e., to the relative locations within the respectively presented global configuration of target and distractors). However, the data also indicate that target expectancies might partly refer to screen locations.

In summary, our results demonstrate that observers adapted to redundant distributions of targets among the positions of the configurations they were embedded in, optimizing the search for them. Observers seemed to accumulate knowledge about where within the configurations the targets in general and which targets in particular occurred and established corresponding expectancies that led to a facilitated recognition of targets where they could be expected. To properly appreciate this ability, one must remember that, especially in the last two experiments, the effective redundan-

<sup>1</sup> The positions of overlapping and nonoverlapping locations on the screen also differed. However, they were located approximately equidistant to the center of the spatial distribution of letters on the screen. Thus, we assumed that the effect of overlapping was primarily driven by target frequencies, not by screen location per se.

cies were hidden in a vast amount of randomness: Both configurations were equally probable. They were presented equally often at two different screen locations. Both target letters appeared equally often. Moreover, they occurred consistently in each of the two configurations. The only redundancy was that one target letter in one configuration and the other target letter in the other configuration was unequally distributed. This is a minor redundancy, in contrast to the redundancy that people are faced with in the distribution of natural stimuli. Nevertheless, the asymmetrical distribution of one respective target in its respective configuration in an otherwise accidental experimental situation was sufficient to produce the strong expectancy effects we consistently observed in all experiments.

We assume that the present settings tap a fundamental and presumably implicit mechanism of the visual system, specialized for the detection of redundancies in the spatial arrangement of stimuli. This speculation is supported by unstandardized interview data we collected from our observers: The majority of the observers in Experiment 3 and 4 were unaware of the redundancy in the target distributions, although the RT data showed clear effects. Recent experiments by Musen (1996) also support this notion of a highly sensitive and presumably implicit learning mechanism. She had participants name either the identity or the location of stimuli that were presented successively within the outline of a rectangle. The location of each stimulus was held constant during a learning phase and changed to random in a subsequent test phase. Musen found that participants were highly sensitive in learning these object–location associations. Even 10 presentations of an object at its location during learning were sufficient to provide a significant increase in naming times in a subsequent test block in which the objects were presented in mismatching locations. Interestingly, learning the stimulus–location associations was explicit under conditions with low attentional load; it was implicit under medium attentional load; and it disappeared under high attentional load. Presumably, the attentional load of the search task in our Experiments 3 and 4 just met this medium level, so that implicit learning of the target distributions occurred. However, these are ad hoc speculations and the issue of whether learning stimulus–location associations are implicit or explicit certainly warrants further investigation.

The results of the present experiments raise a number of other issues that cannot be solved by our data. The first issue concerns whether target expectancies are acquired for all or for only selected locations. In the *Discussion* section of Experiment 1, we pointed out that the interaction between target type and location, found in all four experiments, is consistent with at least two process accounts. First, it can be assumed that the frequencies of targets are concurrently registered for all locations, leading to location-specific expectancies corresponding to the respectively accumulated frequency information (cf. Miller, 1988). To account for the intermediate data pattern we consistently found for the locations directly adjacent to the critical ones, we had to assume that the resulting expectancies were not precisely assigned to single locations but extended to neighboring

locations. Consequently, target recognition in the “adjacent” locations would also be affected by expectancies assigned to their neighboring locations, resulting in an intermediate data pattern. Second, the data are also consistent with the idea that observers acquire target expectancies only for those locations where targets most frequently occur (i.e., for the critical ones): When a configuration is presented, visual attention is assumed to be primarily directed at this location (covertly, overtly, or both), and at the same time the inducing target is expected there. This would account for the general facilitation effect as well as for the more pronounced facilitation for the inducing target in the critical locations. If neither target can be detected, attention is assumed to be directed to other parts of the configuration. Simultaneously, the expectancy for the inducing target is replaced by an expectancy for the alternative test target. To account for the intermediate data pattern for the adjacent locations, it may be speculated that this replacement takes place with a higher probability the more distant from the critical location attention is directed.

Both considerations are in accordance with the present data. Against the latter one, which assumes target expectancies being formed exclusively for locations where targets appear most often, one can refer to the studies of Lambert and Hockey (1986) and Kingstone and Klein (1991). They found that target-specific facilitation effects were also established when stimuli were presented equally often in several possible locations. However, as in these studies, the experimental conditions differed in several aspects from the present settings, as already discussed; further experiments are warranted to clarify this point.

Just as it has to be explored whether for all or only for selected locations stimulus expectancies are established, it remains open whether expectancies are established for all or only for selected stimuli. For example, the results of the present experiments do not allow us to decide whether information about the spatial distribution of stimuli is acquired only for target letters or for distractors. On the one hand, one might argue that for mechanisms such as PSLDs there is no a priori reason to assume why the stimulus type (target vs. distractor) should matter, provided that both types of stimuli are perceived frequently enough. On the other hand, it is also reasonable to assume that only the locations of targets are registered, as target information is necessary and sufficient to give the required response. Pilot studies in our laboratory seem to confirm this latter assumption: In a learning phase, certain distractors were redundantly distributed. These distractors became targets in a subsequent transfer phase. There was no indication that observers profited from the redundant distribution of the targets in the preceding learning phase where they were distractors, suggesting that nothing was learned about the distribution of the distractors. Given these preliminary data, locational expectancies seem to be established only for stimuli that observers are required to respond to.

Finally, the manner in which spatial frame-of-reference target locations are determined also deserves discussion. Although egocentric frames of reference are no doubt useful in a number of tasks (Gordon & Irwin, 1996; Maljkovic &

Nakayama, 1996), they are definitely inappropriate for the extraction of invariances in the location of objects and their parts, as the egocentric locations of objects and parts change whenever the viewpoint changes. Thus, we can assume that the acquisition of knowledge about the location of objects in scenes, or of parts in objects, relies on allocentric reference frames. This consideration is supported by the results of studies indicating the use of allocentric reference systems in object identification (Biederman, 1987; Marr, 1982) as well as in orienting visual attention (Tipper & Behrmann, 1996; Umiltà, Castiello, Fontana, & Vestri, 1995).

The conditions of the present experiments offered two likely allocentric reference frames: the screen and the respective letter configuration the targets were part of. The screen has the advantage of being present throughout the experiment. However, the screen has a disadvantage in that it provides no structured plane on which the targets can be easily located. Furthermore, a comparatively great number of different locations need to be distinguished. For example, in Experiment 3, targets appeared at 27 different screen locations. Configurations, on the other hand, have the advantage of offering a clear structured frame with only a few possible locations. For example, the bird and wave configurations consisted of only seven locations each. This advantage, however, goes along with the disadvantage that the presented configurations always change, so that in each trial the configuration must be identified before it can serve as a frame of reference.

We assume that the influence of different allocentric reference frames on target expectancies is a trade-off between the benefit of higher redundancies of target distributions and the costs of distinguishing between different frames. The results of the present experiments indicate a preference of configural reference frames, but there were also some indications for effects of the screen. These hints were more notable in Experiment 4, in which the effort to distinguish between the configurations was increased by presenting them in different orientations. This observation meets the preceding speculations, but researchers need to conduct more experiments to elucidate the supposed influence of redundancy and discrimination effort on the differential influence of various reference frames on the formation of locational target expectancies.

In summary, we believe that the current experiments addressed a basic visual mechanism that is extremely sensitive for redundancies in the spatial distribution of stimuli and that uses these redundancies for the formation of expectancies for particular stimuli in particular locations. The benefit that an organism gains by such a mechanism is twofold: It reduces the expenditure of the search for details in global structures, and it also supports the recognition of these global structures as individual units such as scenes or objects (e.g., Kosslyn et al., 1990).

Although these speculations seem to be plausible, our experiments also demonstrate the problems that still need to be resolved: Researchers need to investigate whether only for selected or for any locations stimulus expectancies are acquired. Furthermore, they need to explore whether location-specific stimulus expectancies are established only for

selected or for any stimuli (including distractors). Finally, future research has to specify the factors that influence the impact of different reference frames on the formation of location-specific stimulus expectancies. The mechanisms underlying the effects of redundancies in the distribution of visual stimuli will probably adapt in a flexible manner to different conditions. It seems to be beneficial to elaborate further on this adaptation.

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