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Learning to Ignore the Mask in Texture Segmentation Tasks

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Although traditionally texture segmentation has been regarded as an automatic, preattentive process, participants confronted with texture segmentation in experimental settings (i.e., with brief presentation time and subsequent masking) are initially unable to perform the task. According to perceptual learning concepts, participants must learn to fine-tune their sensory channels before perception improves under restricted viewing conditions. The present article proposes an alternative perspective that emphasizes the role of the mask. Four experiments showed that the amount of observed learning depends on the structural and temporal homogeneity or heterogeneity of the mask. The authors suggest that learning consists of separating the task-relevant signal stemming from the texture from the task-irrelevant signal of the mask and of ignoring the mask.

The present article deals with an apparent contradiction with which every researcher of texture segmentation must deal, namely, its automaticity on the one side as compared with the need for practice in experimental settings on the other. Texture segmentation is considered to be a typical example of an early vision process and characterizes the ability to detect an irregularity within an otherwise homogeneous area. Under natural viewing conditions (e.g., when looking at Figure 1), the irregularity can be detected automatically, in other words, without any need for attentional resources. However, when the same stimuli are presented in an experimental situation—that is, for only a brief interval with subsequent masking—performance is rather poor. Participants must have prior knowledge as to what the texture stimuli look like, and they must practice the task before they can perform the texture segmentation. Practice usually involves working on a segmentation task in which the texture stimulus begins with a prolonged presentation time (e.g., 150 ms) that is then reduced successively. After a session of about 1,000 trials with prolonged presentation times, participants usually are able to perform the experimental segmentation task (i.e., texture segmentation with a presentation time of about 40 ms and subsequent masking).

The finding that the texture segmentation task (in the sense just defined) requires practice has been investigated within the broader context of perceptual learning. This term can be traced to Gibson (1969), who defined it as an "increase in the ability to extract information from the environment as a result of practice and experience with stimulation coming from it" (p. 3). Later, the notion was applied to the improvement through practice found in performance on many perceptual tasks, including discrimination of basic visual features such as orientation, spatial frequency or motion direction (Ball & Sekuler, 1987; Fiorentini & Berardi, 1981; Shiu & Pashler, 1992), texture segmentation (Karni & Sagi, 1991), and hyperacuity tasks (Fahle & Edelman, 1993; Herzog & Fahle, 1997; Skrandies & Fahle, 1994; Skrandies, Lang, & Jedynak, 1996; Weiss, Edelman, & Fahle, 1993).

Because perceptual learning is almost always specific to the trained stimulus feature (as found in most of the studies just cited; see, for exceptions, Ahissar & Hochstein, 1995, 1997) and transfers only minimally to the untrained eye (Karni & Sagi, 1991; but, see Ahissar & Hochstein, 1995), untrained stimulus positions (e.g., Karni & Sagi, 1991; Shiu & Pashler, 1992), or untrained features (e.g., Fahle, 1997), it has generally been assumed that perceptual learning takes place rather early in the central visual pathway and can be distinguished from other forms of learning such as that occurring in visual search tasks (e.g., Sireteanu & Rettenbach, 1995; but see Ellison & Walsh, 1998). Therefore, it has been assumed that perceptual learning takes place at an early cortical site, that is, at a level that maintains separate representations for basic visual dimensions such as orientation. Karni and Sagi (1991), for example, proposed that perceptual learning is due to local plasticity within the primary visual cortex. Similar to the original definition by Gibson (1969), they considered perceptual learning to represent an increase in sensitivity induced by sensory experi-

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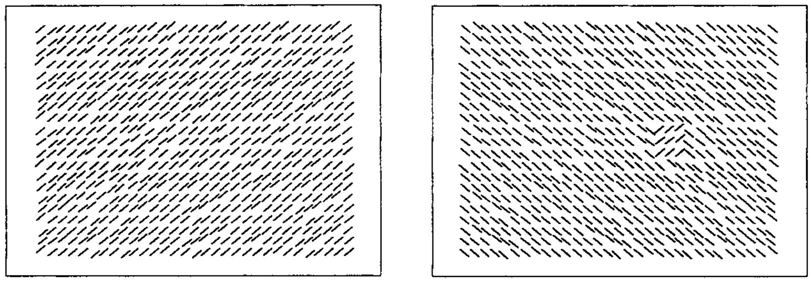

Figure 1. Stimuli used in Experiments 1–5. Left: A homogeneous texture (i.e., a texture without a target). Right: A heterogeneous texture (i.e., a texture with a target). The target could appear at different locations along the horizontal meridian.

ence. Here we term this interpretation of perceptual learning the *early-modification hypothesis.*

Recently, the perceptual learning concept has been broadened through studies showing that higher level processes such as attention (Ahissar & Hochstein, 1995, 1997; Herzog & Fahle, 1998; Rubin, Nakayama, & Shapley, 1996; Weiss et al., 1993) and intention (Shiu & Pashler, 1992) also play a role in improving performance on perceptual tasks. Shiu and Pashler (1992), for example, found no improvement in the discrimination of a line's orientation when orientation was not task relevant. In one of their experiments, participants had to discriminate the line's brightness while receiving no instruction on orientation. In this case, no improvement in orientation discrimination was found. Hence, perceptual learning seems to occur only when the dimension is also task relevant. Ahissar and Hochstein (1995) reported similar results in a task with texture stimuli. They trained participants to identify the orientation of an entire texture array before comparing their performance with that of untrained participants. Performance on the subsequent texture segmentation task differed only slightly in the two groups, indicating that training with texture stimuli led to only a small improvement when texture segmentation was not task relevant. Note that these results do not contradict the early-modification hypothesis, because perceptual learning is still assumed to reflect increased sensitivity in the primary visual cortex. This improvement, however, does not seem to arise without the intention of attending to the relevant stimulus dimension. Thus, the perceptual learning concept now differs from the original notion by including higher level processes that do not stem purely from the stimulation itself. We term this broader interpretation of perceptual learning the *higher level involvement hypothesis.*

Ahissar and Hochstein (1997) refined the higher level involvement hypothesis by postulating that a top-down impulse is necessary in difficult learning situations (i.e., with small orientation differences between target and context, many possible stimulus locations, and a short stimulus–mask interval), whereas improvement can be achieved simply by repeated stimulus presentation in easy learning situations (i.e., 90° orientation differences, two possible stimulus locations, and a longer stimulus–mask interval). They showed that, in difficult cases, a single top-down impulse suffices for perceptual improvement (and thus learning) to occur. No improvement occurred when participants had to perform the task without prior presentation of the stimuli. Nonetheless, when participants were presented with the stimuli for a long period (30 s) in advance, performance improved. Thus, the single presentation of the stimulus enabled perceptual learning, a phenomenon termed the *eureka* effect by Ahissar and Hochstein (1997). We term this modified version of the higher level involvement hypothesis claiming that higher order processes are necessary to enable learning (at least in difficult learning situations) the *enabling hypothesis.*

Despite the differences in theoretical concepts of perceptual learning, there is agreement that some prior information on the stimuli is necessary to initiate the learning process. Therefore, participants are usually familiarized with the to-be-segmented texture stimuli, either through extended presentation (as in the eureka procedure used by Ahissar & Hochstein, 1997) or by first practicing the task with a prolonged stimulus presentation time, set individually for each participant (operationalized by increasing the stimulus–mask onset asynchrony [SOA] to about 150 ms). Once participants are able to perform the task with an accuracy of 80%–90%, the SOA is reduced step by step until about 40 ms (Ahissar & Hochstein, 1995; Karni & Sagi, 1991). Whereas extended presentation time is believed necessary to enable perceptual learning (Ahissar & Hochstein, 1997), practicing the task with a prolonged SOA is considered necessary to allow the system to activate the categories relevant for the segmentation (Karni & Sagi, 1991). Therefore, all theories of perceptual learning in texture segmentation tasks postulate implicitly that an extended or prolonged presentation time is necessary for participants to perform the segmentation task under experimental constraints. Our first experiment was designed to test this assumption explicitly.

A second common aspect of theories of perceptual learning in the context of texture segmentation is their concentration on the first stimulus, the texture stimulus, and its attributes such as orientation differences between target and context, array size, number of possible target locations, and presentation time. However, the experimental situation permits another perspective on possible learning effects. Imagine the following situation in a texture segmentation task (i.e., texture segmentation under experimental constraints): A texture is presented for a short time and subsequently replaced by a stimulus of the same (or a larger) spatial extent presented at the same position, the mask. We wish to draw attention to the second stimulus in the sequence, namely, the mask. We want to suggest a concept of learning that differs from the perceptual learning concepts described earlier through its emphasis on the role of this mask in the learning situation. We propose that participants in texture segmentation tasks learn to suppress, ignore, or filter out the second, task-irrelevant stimulus as they proceed to perform the task. We term this notion the *mask-ignoring hypothesis.*

Experiment 1: No Prior Knowledge of Texture Stimuli

The first experiment investigated whether segmentation of texture stimuli in an experimental situation (i.e., with a brief presentation time and subsequent masking) would also be possible without any prior knowledge about the stimulus material and without any practice trials with prolonged stimulus presentation. Naive participants were given no information about the texture stimuli used, and presentation time was set immediately to 33 ms. If learning is possible under these conditions, it would not depend, at least not entirely, on top-down enabling (Ahissar & Hochstein, 1997) or preactivation of categories relevant to the segmentation task (Karni & Sagi, 1991).

Method

Participants. Ten paid volunteers (6 men, 4 women; *M* age: 29.2 years) participated in the experiment. All but one were right-handed, all had normal or corrected-to-normal vision, and none had participated in a texture segmentation experiment before.[1]

Stimuli and apparatus. The texture stimuli comprised a matrix of 31 × 21 elements subtending a visual angle of 19° × 13°. Elements were oblique lines tilted 45° either to the right or left (see Figure 1). Lines were approximately 0.7° long and approximately 0.1° wide. The distance between adjacent lines was approximately 0.62° horizontally and vertically (measured from center to center). A jitter was imposed on the texture stimuli so that each element was randomly displaced by 0° or by ±0.1° horizontally or vertically. Texture stimuli were either homogeneous (consisting of leftward- or rightward-tilted elements only) or heterogeneous. Heterogeneous texture stimuli contained an array of 3 × 3 elements (termed *target*) made up of lines tilted in the direction opposite the surrounding elements. The target appeared randomly at one of 25 possible locations horizontally displaced in steps of 0.7° to the left or right of the center of fixation (center also included).[2] Textures composed of leftward- or rightward-tilted elements appeared with equal probability throughout the experiment. Masking stimuli were constructed by superimposing a leftward-tilted on a rightward-tilted homogeneous texture (see Figure 2). In addition to the texture stimuli, participants also viewed a ready sign (a question mark subtending a visual angle of approximately 0.7° × 0.5°) and a fixation point (subtending a visual angle of approximately 0.1° × 0.1°). Stimuli were presented on a 17-in. (43-cm) low-emission computer screen and appeared in black on a light-gray background (luminance about 37 cd/m^2).

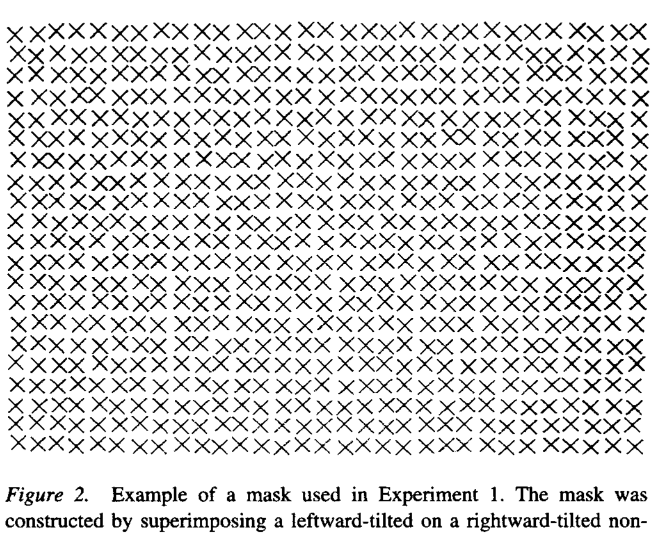

Figure 2. Example of a mask used in Experiment 1. The mask was constructed by superimposing a leftward-tilted on a rightward-tilted nontarget texture.

Procedure. Participants were seated in a dimly lit, sound-attenuated chamber with response buttons under their left and right index fingers 60 cm from the computer screen. Stimuli appeared directly in front of the participants at the center of their field of vision.

The experiment was divided into three parts (delivered on 3 successive days) of 10 blocks each. Each experimental block contained 100 trials. A trial began with the presentation of the ready sign at the center of the screen. Participants could then initiate the trial by pressing both response buttons simultaneously. The ready sign was then replaced by the fixation point, which, after 700 ms, was replaced in turn by the texture stimulus. In one half of the trials, a homogeneous texture was presented; in the other half, a heterogeneous texture was presented (that is, a texture containing a target). Targets appeared at each of the 25 locations with equal probability. After 33 ms, the texture stimulus was replaced by the mask, which remained visible until one of the two response buttons was pressed. Participants had to respond with a right button press for a target; otherwise, they responded with a left button press. After the response, the masking stimulus was replaced by the ready sign, and the next trial could be initiated.

Participants were given no advance information about the stimuli used in the experiment. They were not shown examples of homogeneous or heterogeneous textures, and they were not informed that textures were composed of oblique lines. Instead, they were told that a homogeneous area would be presented briefly before the mask that could contain an inhomogeneity or irregularity on one half of the trials. Their task would be to try to indicate whether such an irregularity was present or not. As a means of minimizing the false alarm rate, participants were strongly encouraged to provide a present response only when they were sure of having detected an irregularity (i.e., the target) and to favor an absent response if they were in doubt. At the end of each block, participants were informed about their number of hits and false alarms.

Data analysis. Before the analysis, mean reaction times and standard deviations were computed for each experimental block and for each participant. Those trials on which RT was more than three standard deviations above or below mean RT were dropped from the analysis (altogether, fewer than 2.5% of trials were excluded from data analysis in all of the experiments). Mean correct response rate was determined for both nontarget and target trials, along with false alarm rate. To determine the time course of learning, we conducted separate linear regression analyses for both hit rate and false alarm rate in each of the three sessions, collapsed across the different target location conditions. This was done for each participant individually. Three one-sample *t* tests (one for each session) were conducted to determine whether the mean slopes of the participants' regression curves differed significantly from zero. Furthermore, a repeated measures analysis of variance (ANOVA) was conducted to test whether slopes differed significantly among the three sessions, thus indicating that learning differed between sessions.

[1] Visual acuity was tested with a Rodenstock R12 vision tester. All participants took this test before starting the experiments.

[2] Peripheral locations were chosen because segmentation performance is known to depend on retinal eccentricity (best performance around 3°–6°; central [foveal] performance drop; e.g., Gurnsey, Pearson, & Day, 1996; Joffe & Scialfa, 1995; Kehrer, 1987, 1989; Meinecke & Kehrer, 1994; Yeshurun & Carrasco, 1998).

Results and Discussion

There was a substantial increase in the hit rate during the first experimental session, indicated by a mean slope of 3.65 for the participants' linear regression curves, $t(9) = 3.27$, $p = .005$ (see Figure 3). Moreover, the hit rate tended to increase further throughout the second session (mean regression slope of 1.68), $t(9) = 2.14$, $p = .030$, and third session (mean regression slope of 0.75), $t(9) = 2.12$, $p = .031$. Although all slopes were positive, the repeated measures ANOVA revealed a decrease in slopes across sessions, $F(1, 9) = 6.42$, $p = .032$, indicating that there was less learning in the third than the first session.

The decrease in the false alarm rate was most pronounced during the second session (regression slope of -0.72), $t(9) = 1.94$, $p = .042$, whereas there was virtually no decrease in the false alarm rate during the first and third sessions (slopes of -0.29 and -0.18, respectively; $t < 1$). Furthermore, the ANOVA revealed no significant differences in the mean slopes of the three sessions ($F < 1$). There were major interindividual differences in learning over sessions. Whereas 5 participants already showed a substantial increase in their hit rate (and a substantial decrease in their false alarm rate) during the first session, 2 participants showed a substantial (and stable) performance increment only in the second or third session, and 3 participants showed neither an increase in hit rate nor a difference between hit rate and false alarm rate (see Figure 4).

Experiment 1 shows that learning—operationalized as an increase in hit rate and a decrease in false alarm rate—did occur in the first session, even though participants neither had prior knowledge about the stimuli used nor were given a practice phase with prolonged stimulus presentation times. The learning rate (for 7 of 10 participants) was comparable to that usually found in traditional procedures with prior stimulus information and extended presentation times. Thus, one could state that, in the present experiment,

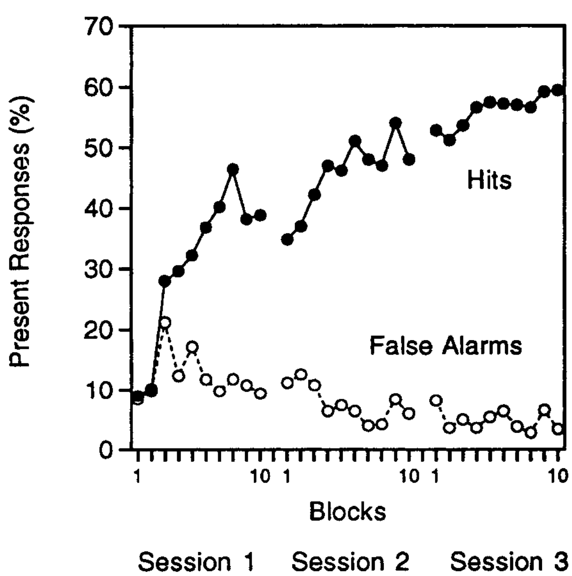

Figure 3. Results of Experiment 1: Percentage of present responses (ordinate) across all three sessions (abscissa) for hits (solid circles) and false alarms (open circles).

it was neither necessary to enable perceptual learning through prior stimulus presentation (Ahissar & Hochstein, 1997) nor to practice the task with a prolonged SOA to preactivate features or categories relevant to the segmentation task (Karni & Sagi, 1991). Instead, most participants were able to segment the textures without even knowing what they looked like. Experiment 1 thus shows that an improvement in texture segmentation in the experimental setting can—at least with some textures—be independent of the information given about the texture stimulus and is also possible with a short presentation time.

Because it is known that the detection rate of textures with orientation differences varies as a function of the retinal eccentricity of the target (central performance drop; see Footnote 2), one possible objection is that top-down activation might have taken place indirectly in Experiment 1: If some privileged positions had already produced higher detection rates at the beginning of the experiment, these positions could have operated as enabling stimuli and led to the activation of top-down processes. However, an analysis of the distribution of hits in the first block revealed no evidence for different detection performance at different target positions.

The enabling hypothesis (Ahissar & Hochstein, 1997) might try to explain the results of the present experiment differently: It could state that because our stimuli were textures with a clear pop-out target, the segmentation, as well as the learning situation, was rather easy. Therefore, no top-down enabling was needed for learning to occur. Because Experiment 2 was designed to shed light on this question, we return to this objection in the discussion of Experiment 2.

Experiment 2: Learning Depends on the Mask as Well

The results of Experiment 1, showing that the texture segmentation task can be learned without any prior knowledge about the presented texture stimuli, lead us to ask what exactly caused this improvement. Looking back at the experimental situation and recalling that texture segmentation can be performed effortlessly when the texture is not masked, one could speculate that participants have to learn to ignore the mask in the experimental situation. This might have been the case in Experiment 1. Experiment 2 was conducted to investigate whether the mask has any influence on the learning process in texture segmentation tasks. Therefore, we left the texture stimuli unchanged but designed a completely different mask. It was constructed by randomly merging horizontal, vertical, and oblique lines (tilted 30° to the left or right) and dots, generating a different combination of these elements for each of the 651 cells of the mask. We termed this construction the *scrambled pattern mask* (SPM; see Figure 5). The SPM was refreshed after each trial, yielding a new SPM for the next trial. The SPM differed somewhat from the mask used in Experiment 1, whereas the texture stimuli stayed the same; thus, if a different pattern of learning were to occur, one could attribute this difference to the different masks.

Method

Participants. Ten paid volunteers (3 men, 7 women; *M* age: 24.3 years) participated in the experiment. All were right-handed, had normal or corrected-to-normal vision, and had never before participated in a texture segmentation experiment.

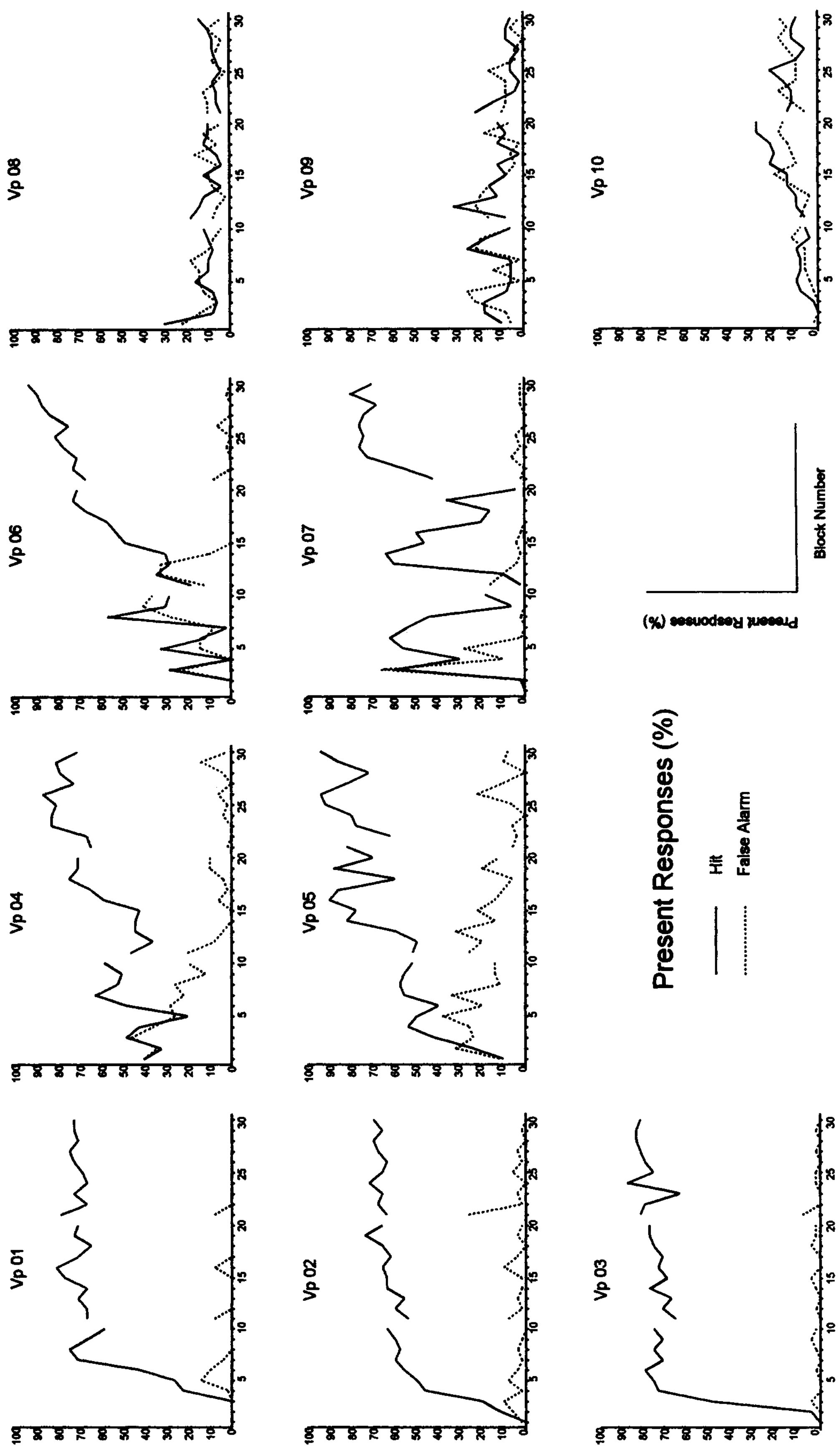

Figure 4. Results for each participant in Experiment 1: 5 participants improved in the first session (Vp01–Vp05), 2 participants improved in the second or third session (Vp06 and Vp07), and 3 participants did not improve at all across sessions (Vp08–Vp10).

Stimuli and apparatus. The apparatus was the same as in Experiment 1, and the texture stimuli were also left unchanged, except that the target could now appear at one of five possible locations (in the center or horizontally displaced 2.9° or 5.6° to the left or right). The SPM (as described earlier) was renewed on each trial.

Procedure and data analysis. The procedure and analysis were the same as in the first experiment.

Results and Discussion

Results are depicted in Figure 6. There was a slight but nonsignificant decrease in hit rate during the first two experimental sessions, indicated by mean slopes of −0.52 and −0.3 in the respective linear regression curves ($t < 1$) and a small increase in the third session that failed to attain significance (mean slope of 0.92), $t(9) = 1.65$, $p = .064$. The false alarm rate mirrored the results for the hit rate, namely, a decrease in the first two sessions followed by an increase in the third (slopes of −0.76, −0.80, and 0.75, respectively). None of the slopes were significant ($ts < 1.3$, $ps > .12$). The ANOVA revealed no differences between slopes across sessions for either hits or false alarms. Because learning would be indicated by an increase in the hit rate and a simultaneous decrease in the false alarm rate, and there was no difference between hit rate and false alarm rate during all experimental sessions, one could state that no learning took place in Experiment 2. None of the participants showed any learning effects.

The second experiment was conducted to investigate whether the mask might be involved in the learning process in texture segmentation tasks. The results of both the first and the second experiments clearly indicate that the mask is a necessary factor for learning effects to occur. Because everything else in the stimulus material as well as the procedure (e.g., texture presentation time) was unchanged in both experiments, the lack of any improvement in Experiment 2 relative to the improvement found in Experiment 1 would seem to be due to the use of different masks.

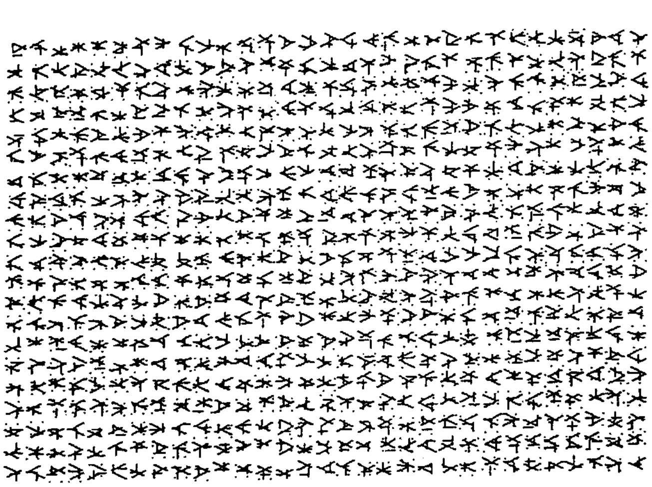

Figure 5. Example of a scrambled pattern mask (SPM) used in Experiment 2. The SPM was constructed by randomly drawing elements out of sets containing horizontal, vertical, and oblique lines and dots, generating a different combination of these elements for each of the 651 cells of the matrix.

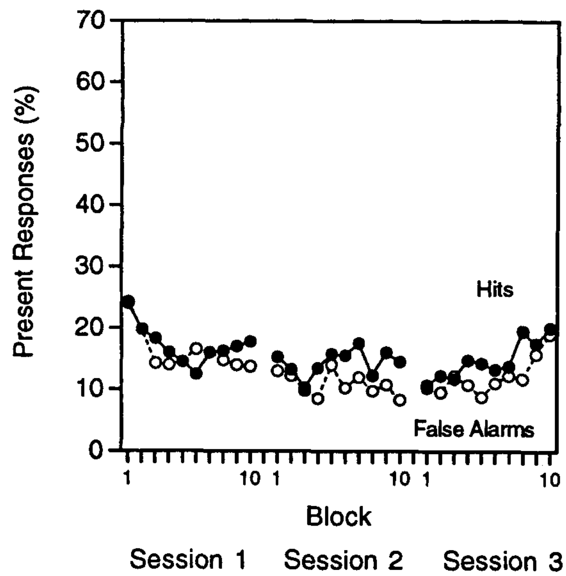

Figure 6. Results of Experiment 2: Percentage of present responses (ordinate) across all three sessions (abscissa) for hits (solid circles) and false alarms (open circles).

When discussing Experiment 1, one possible objection derived from the enabling hypothesis (Ahissar & Hochstein, 1997) was reported: Because our stimuli were textures with a clear pop-out target, the learning situation was rather easy, and top-down enabling would not have been necessary for learning to occur. This objection could explain the results of Experiment 1 but not those of Experiment 2. Because the textures were identical in both experiments, one would, according to the objection, expect learning to have occurred in Experiment 2 as well. However, this was not the case.

The results of Experiment 2 rule out a further explanation of the learning effects found in Experiment 1, namely, that prolonged training per se might have led to a fine-tuning of the sensory channels even without prolonged presentation of the texture stimuli. If this was the case, one would have expected the same learning effects to occur in Experiment 2 because of the identical procedure.

One account for the results of both Experiments 1 and 2 could be derived from the early-modification hypothesis (Karni & Sagi, 1991). This might claim that the amount of preactivation of categories relevant for performing the texture segmentation task differed in the two experiments. Because the mask in Experiment 1 was generated by superimposing the texture stimuli, it could be used to preactivate the features of the texture stimuli.[3] No such preactivation was possible with the mask in Experiment 2, and thus the differences in improvement found in the two experiments might simply be due to the different amount of mask-induced preactivation of the relevant categories. This idea was tested in Experiment 3.

[3] We are aware that the system-internal stimulus representation in preattentive or early vision is not necessarily a one-to-one depiction of the physical stimulus. Psychophysical data (e.g., Meinecke & Kehrer, 1994;

Despite this objection, it seems justified to state that it was the mask rather than the stimulus that influenced the results of Experiments 1 and 2. This conclusion does not rule out the existence of other forms of perceptual learning as postulated by the early-modification hypothesis or the enabling hypothesis. Our results extend these concepts by emphasizing the role of the mask in perceptual learning tasks.

Irregularity Detection and the Structure of Masks

Because learning was found only with the mask used in Experiment 1 and the structure of the masks differed between Experiments 1 and 2, it seemed worthwhile to investigate the structures of the masks used in more detail. One way to describe the masks is in terms of their local and global structures. Both masks are generated in a similar way to the texture stimuli: They consist of an area formed by 651 cells and have the same spatial extent as the preceding texture stimulus. We use the terms *local* and *global* as follows: *Local* refers to the structure of a single cell of the mask, whereas *global* refers to all of the cells of the mask simultaneously. With regard to a single cell of the mask (i.e., its local structure), the mask in Experiment 1 was constructed of two elements (a leftward and a rightward tilted line) arranged to form an x-like element. A single cell of the mask used in Experiment 2, on the other hand, consisted of five elements arranged in a random way. When all cells of the matrix are considered simultaneously (i.e., its global structure), the content of the cells can either remain constant or differ from cell to cell. When all 651 cells of the mask contain the same elements (as in Experiment 1), one could say that the global structure is regular (or homogeneous). However, when the arrangement of elements within each cell differs (as in Experiment 2), the global structure is irregular (or heterogeneous). According to these definitions, the masks in Experiments 1 and 2 differ with respect to both their local (i.e., when regarding a single cell) and global (i.e., when regarding all cells) structures.

We assume that the more homogeneous or regular the mask, the more learning will be observed. This premise can be explained as follows: According to the view that gradients play a critical role in texture segmentation tasks (Nothdurft, 1985; Nothdurft, Gallant, & Van Essen, 1999; Rubenstein & Sagi, 1993; Sagi & Julesz, 1987), we assume that the task in our experiment is to detect an irregularity within an otherwise homogeneous area. In our paradigm, the texture stimulus is followed immediately by a mask. We postulate that the detection of an irregularity will be less disturbed by a regular, homogeneous mask than by a mask that is rather heterogeneous. When a homogeneous mask is used, the irregularity-detection process will be activated only by the texture. When a heterogeneous mask is used, however, the irregularity-detection process will be triggered by both the texture and the mask. Therefore, in the case of a homogeneous mask, the detection of an irregularity always signals the presence of an irregularity in the texture (i.e., a target). In the case of a heterogeneous mask, in contrast, detection of an irregularity is not a valid indicator of the presence of a target in the texture.

In looking at the learning situation, things might be as follows: With a homogeneous mask, one has to learn to detect an irregularity in the experimental setting (i.e., with short presentation and subsequent masking). With a heterogeneous mask, one also has to learn to discriminate between two (perhaps very similar) irregularity signals. The results of Experiment 2 suggest that it is almost impossible to learn to discriminate between these two irregularity signals when they are presented in close temporal order. One might object that the lack of learning in Experiment 2 was due to the short SOA used. However, because exactly the same SOA was used in Experiment 1, in which learning was observed, the short SOA cannot account for the difference in the results of Experiments 1 and 2. Instead, we propose that the difference in the structure of the masks was responsible for the different learning effects. In fact, learning should occur with any homogeneous mask regardless of whether or not the mask is similar to the texture stimuli.

Experiment 3: Homogeneity of the Mask Allows Learning

Experiment 3 investigated whether a homogeneous mask would allow learning. For this purpose, a homogeneous SPM was constructed that was constant across all cells of the matrix; that is, the SPM had the same spatial arrangement of elements in all cells. This mask should not trigger an irregularity-detection process, and learning should occur.

Experiment 3 also permitted a test of the preactivation hypothesis that the differences in learning found between Experiments 1 and 2 might have been due to the mask in Experiment 1 containing the same elements as the texture stimuli, thus leading to a preactivation of the features relevant to perform the task. Because this was not the case for the mask in Experiment 2, the lack of any learning in that experiment might have been due simply to the impossibility of preactivating stimulus features through the mask. Because the mask in Experiment 3 contained none of the features of the texture stimuli, thus rendering any preactivation impossible, the preactivation hypothesis would predict that no learning should occur.

Method

Participants. Ten paid volunteers (4 men, 6 women; *M* age: 24.5 years) participated in the experiment. All were right-handed, had normal or corrected-to-normal vision, and had never before participated in a texture segmentation experiment.

Stimuli and apparatus. The apparatus was the same as in Experiment 2. In addition, texture stimuli were unchanged except that the target could now appear at one of seven possible locations (in the center or horizontally displaced by 2.9°, 4.9°, or 6.3° to the left or right). The masking stimulus

Meinecke, Kimchi, & Grandegger, 2000) as well as results from quantitative models of texture segmentation (e.g., Malik & Perona, 1990; Rubenstein & Sagi, 1990) support this view. It could be inferred that a mask consisting of the superimposed texture stimuli (/- and \-texel yielding X-texel) is not able to preactivate relevant categories, because their system-internal representation no longer contains the orientation information of the two diagonal lines. This is certainly true when analyzing the resulting power spectra for large wavelengths; however, the power spectra for shorter wavelengths still contain the orientation of the two diagonal lines. Because we assume, in line with Kehrer (1997), that the stimulus is analyzed not only with one type of filter but, as a function of eccentricity, with filters of increasing wavelength, it is probable that the texels of the mask are—at least in the foveal area—perceived as two superimposed lines. This should be all the more the case because the mask was presented without time limitation.

was a homogeneous SPM (hSPM; see Figure 7) constructed in a similar way to the SPM in Experiment 2. However, the same spatial arrangement of one horizontal, vertical, oblique, left- and right-tilted line and dots was chosen for each of the 651 cells of the mask. The hSPM was renewed on each trial.

Procedure and data analysis. The procedure and analysis were the same as in the prior experiments.

Results and Discussion

The results are depicted in Figure 8. As in Experiment 1, there was a substantial increase in the hit rate in the first session, indicated by a slope of 3.02 in the respective linear regression curve, $t(9) = 2.10$, $p = .032$. The hit rate increased further throughout the second session (slope = 0.91), $t(9) = 2.07$, $p = .034$. However, the increase in the third session failed to attain significance (slope = 0.50), $t(9) = 1.61$, $p = .071$. The ANOVA indicated no significant difference in slopes between sessions ($p > .14$).

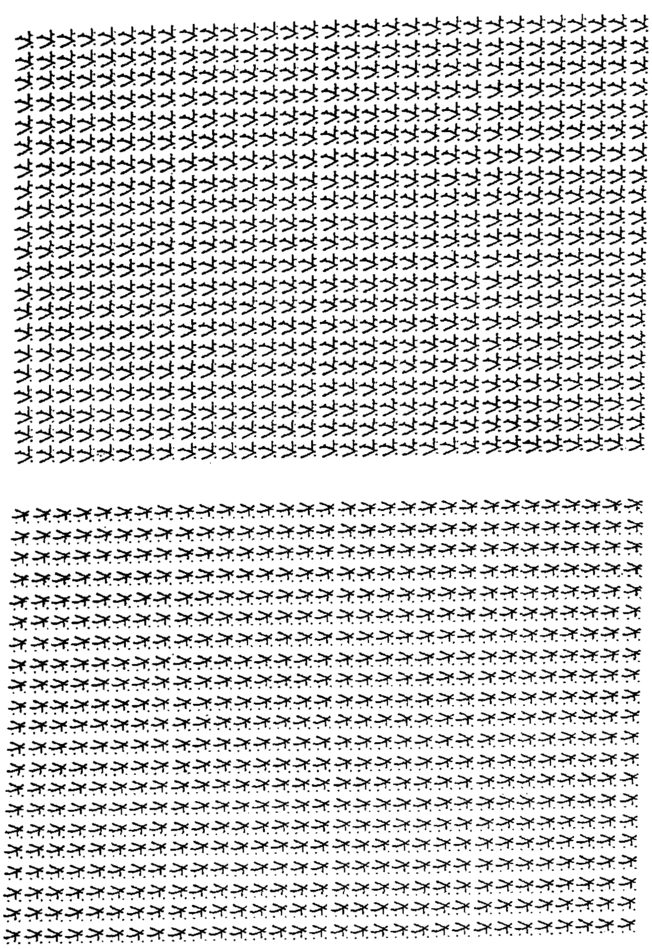

Figure 7. Examples of homogeneous scrambled pattern masks (hSPMs) used in Experiment 3. The hSPMs were constructed exactly as the SPM in Experiment 2. However, the same spatial arrangement of random lines and dots was used for each of the 651 cells of the matrix. For each trial, a different random combination was chosen.

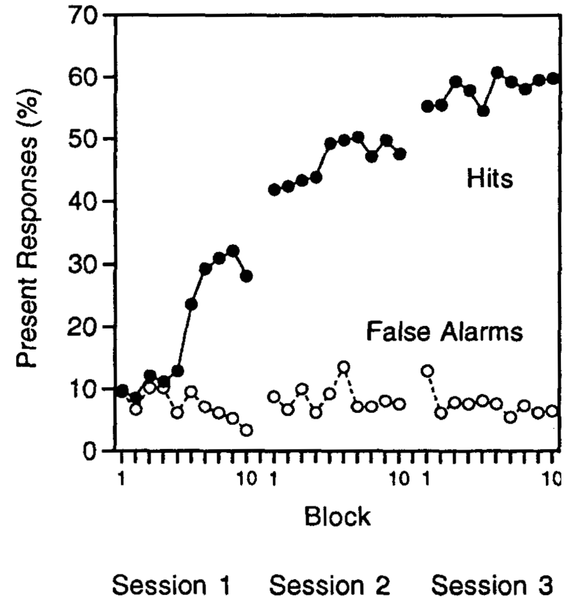

Figure 8. Results of Experiment 3: Percentage of present responses (ordinate) across all three sessions (abscissa) for hits (solid circles) and false alarms (open circles).

The false alarm rate revealed no significant decrease for the first two sessions (regression slopes of −0.56 and −0.72, respectively), $t < 1.1$, $p > .15$. However, the decrease was significant in the third session (mean slope −0.42), $t(9) = 2.98$, $p = .007$. The ANOVA revealed no significant effect.

As in Experiment 1, there were differences among individual participants. The learning rate (for all 10 participants) seems to indicate that Experiment 3 may have been even easier than Experiment 1. This may well have been true, because the mask in Experiment 1 showed some irregularity, with the positions of the x-like elements forming the mask varying slightly from cell to cell (see Figure 2).

The results of Experiment 3 clearly show that learning is possible with a mask that contains none of the features of the texture stimuli. The preactivation hypothesis was thus not validated. Moreover, Experiment 3 shows that learning is possible with a mask that is homogeneous in terms of its global structure. The results support the assumption that homogeneous masks do not trigger an irregularity-detection process similar to the irregularity-detection process triggered by the texture. Therefore, detection of an irregularity can be related exactly to the target in the texture. Under this condition, learning can occur.

In the next experiment, we wanted to investigate an additional aspect of homogeneity. In the previous experiments, masks were characterized in terms of their spatial homogeneity. This was emphasized by creating a new mask on every trial; in other words, in all experiments, temporal inhomogeneity or irregularity was maximal. However, one may ask whether temporal regularity might have a facilitatory effect on learning similar to that found for spatial regularity. This was investigated in the following experiment.

Experiment 4: Constancy Over Time

Experiment 4 repeated both Experiments 2 and 3 without any changes in experimental design except that the mask was held constant throughout the experiment for each individual participant (but was still varied between participants). Comparing the results of this experiment with those of Experiments 2 and 3 would make it possible to determine the impact of temporal regularity on learning.[4]

Method

Participants. Twenty paid volunteers (9 men, 11 women; *M* age: 24.0 years) participated in the experiment. All were right-handed, had normal or corrected-to-normal vision, and had never before participated in a texture segmentation experiment.

Stimuli and apparatus. The apparatus and texture stimuli were the same as in Experiment 3. The masking stimulus was either an SPM constructed as in Experiment 2 (see Figure 5) or an hSPM constructed as in Experiment 3 (see Figure 7). Ten of the participants were confronted with an SPM, and the other 10 were confronted with an hSPM. The given mask remained constant across all trials in the three sessions for each individual participant.

Procedure and data analysis. The procedure and analysis were the same as in the first experiment. Regressions and *t* tests were calculated separately for the hSPM and the heterogeneous SPM.

Results and Discussion

The results of Experiment 4 are depicted in Figure 9. The upper panel shows results for the hSPM; the lower panel shows results for the SPM. Both experimental conditions revealed a difference between hit rate and false alarm rate, indicating that some learning had occurred. However, the effect was much larger when an hSPM was used (upper panel of Figure 9) than when the heterogeneous SPM was used (Figure 9, lower panel). With the hSPM, the hit rate increased significantly in the first session (slope = 3.28), $t(9) = 2.27$, $p = .024$. The increases in the second and third sessions were not significant (mean slopes = 1.10 and 0.37, respectively; $p > .10$). The difference in mean slopes between sessions also failed to attain significance ($p > .09$). The rate of false alarms decreased significantly in the first session (mean slope = -1.32), $t(9) = 4.07$, $p = .001$, but the decrease no longer attained significance in the later sessions (slopes = -0.35 and -0.24, respectively), $t < 1$, $p > .18$. The difference in mean false alarm rate slopes was barely significant across sessions, $F(1, 9) = 4.99$, $p = .052$, indicating that the decrease in false alarms was observed mainly in the first session.

The heterogeneous SPM revealed a moderate increase in hit rate for all three sessions. This increase attained significance in the second and third sessions: The mean slope was 1.1 for the first session ($p > .09$); the mean slope was 1.45 for the second session, $t(9) = 1.78$, $p = .050$; and the mean slope was 0.77 for the third session, $t(9) = 2.46$, $p = .018$. The ANOVA revealed no significant difference between slopes. During the first session, the false alarm rate remained almost unchanged (mean slope = -0.094; $t < 1$), but it increased slightly in Sessions 2 and 3 (mean slopes = 1.2 and 0.63, respectively). Neither increase was significant ($p > .07$ for the second session and $t < 1$ for the third session). Furthermore, the ANOVA revealed no significant effects ($F < 1$). Because an increase in hit rate was observed, whereas the false alarm rate did not change, some learning took place. Whereas 9 of 10 participants showed learning with the hSPM, only 3 of 10 learned with the heterogeneous SPM.

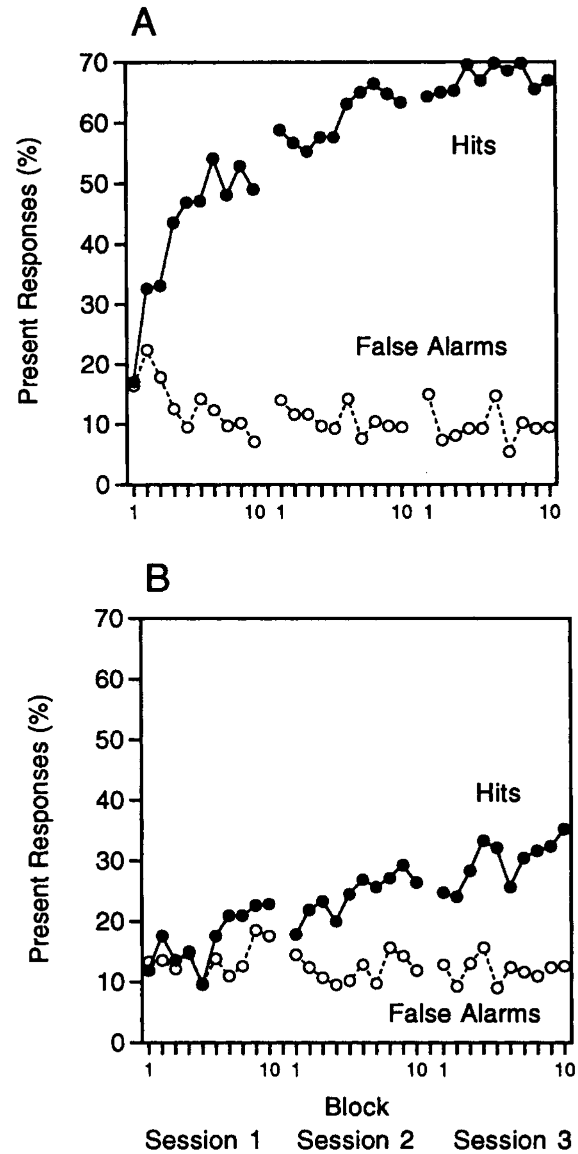

Figure 9. Results of Experiment 4. A: Results with the homogeneous scrambled pattern mask. B: Results with the heterogeneous scrambled pattern mask.

Experiment 4 shows that constancy over time can also influence learning. A comparison between the results found with the heterogeneous mask and the results of Experiment 2 reveals clearly that regularity over time can be used to improve performance. The same was observed for the hSPM in a comparison with the results of Experiment 3.

[4] Although it seemed somehow paradoxical to repeat Experiment 3, in which performance was already near ceiling under what can be considered to be even more difficult learning conditions (because the mask was renewed on every trial), we believed it necessary both for the sake of completeness and to guarantee that no diverging results would be observed. In the worst case, the hSPM condition can be regarded as a replication of Experiment 3.

Experiment 5: How Experts Perform

During our experiments, we made an interesting observation, namely, that individuals familiar with texture segmentation tasks had no problems in detecting the target within the texture when the texture was masked by the heterogeneous SPM. This was quite astonishing, because learning was hardly possible with this mask for novice participants (Experiments 2 and 4).

This observation was tested systematically in Experiment 5. There were two groups of participants. The first group, termed *experts,* consisted of people who had participated in many texture segmentation experiments over several years. The second group, termed *practiced participants,* consisted of those participants in Experiment 4 who had worked with the hSPM. This second group was included in the experiment because its members had only limited prior experience with texture segmentation. Moreover, we had precise information about their learning history because they had taken part only in Experiment 4.

We wanted to know whether experts would be able to perform the task with a heterogeneous SPM. Furthermore, we believed that it would be interesting to look at differences between the performance of experts and practiced participants.

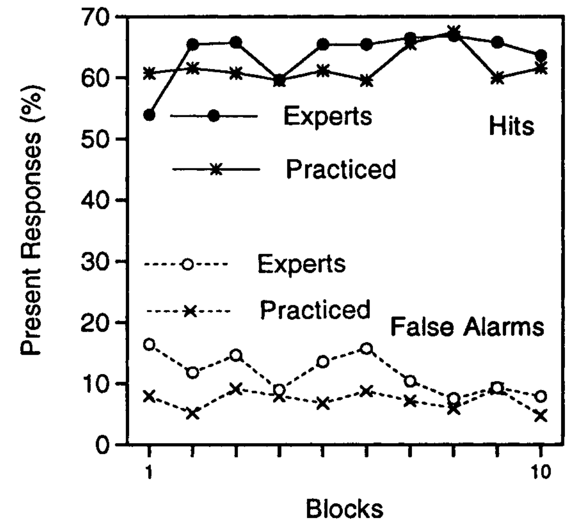

Figure 10. Results of Experiment 5: Performance of experts (circles) compared with performance of practiced participants (crosses).

Method

Participants. Two groups of participants took part in the experiment: the expert group (8 participants; 3 men, 5 women; *M* age: 35.8 years) and the practiced group of 9 participants from Experiment 4 (3 men, 6 women; *M* age: 22.8 years). All were right-handed and had normal or corrected-to-normal vision.

Stimuli and apparatus. The stimuli and apparatus were the same as in Experiment 2.

Procedure and data analysis. The procedure and analysis were also the same as in the prior experiments, except that there was only one session with 10 experimental blocks. The differences in mean slopes between the two groups were tested instead of differences in mean slopes between sessions. In addition, the difference between hits and false alarms for the groups in the first block was examined with a paired t test.

Results and Discussion

The results of Experiment 5 are depicted in Figure 10. Both groups already showed a large difference between hit rate and false alarm rate in the first block of the session, as indicated by the paired t test: $t(7) = 5.12, p = .001$, for experts and $t(8) = 4.31, p = .003$, for practiced participants. The hit rate did not change significantly during the session for either experts or practiced participants (slopes = 0.54 and 0.13, respectively; both $ts < 1$). However, there was a small but significant decrease in false alarm rate in both groups: experts, slope = -0.83, $t(7) = 2.38, p = .024$, and practiced participants, slope = -0.33, $t(8) = 2.24, p = .027$. The differences in mean slopes between the two groups for both hit rate and false alarm rate did not attain significance ($p > .19$).

Experiment 5 shows that participants familiar with texture segmentation tasks can perform the tasks even with a mask that is so heterogeneous that it makes learning for novices impossible (see Experiment 2). Interestingly, the same is true for the practiced participants who had taken part in only one texture segmentation experiment before, namely, in the hSPM condition in Experiment 4. Thus, practice with a homogeneous mask is sufficient for successful performance of the task with the heterogeneous SPM, even when the mask is renewed on each trial. The results confirm the observation that experts have no difficulties with the heterogeneous structure of the SPM. Moreover, practiced participants had no problem in performing the task despite their minimal experience and the fact that they have never before practiced with the heterogeneous SPM. Because their amount of experience was restricted and controlled, participants must have learned something in Experiment 4 that could be transferred and facilitated performance in Experiment 5.

General Discussion

This article has examined what must be learned to perform texture segmentation under experimental constraints, that is, with brief stimulus presentation and subsequent masking. The fact that texture segmentation requires a degree of learning in the experimental situation is quite puzzling, because the same task can be performed effortlessly and automatically under nonrestricted viewing conditions. Suggestions as to why learning is necessary and what has to be learned can be found within the perceptual learning literature. It has been suggested that participants have to fine-tune their sensory channels to perform the task and that this fine-tuning can be achieved by initially training the task with prolonged presentation times (e.g., Karni & Sagi, 1991). It has also been suggested that learning has to be enabled by higher level processes, and prior information on the stimuli must be given to participants (at least in difficult learning situations) for learning to occur (e.g., Ahissar & Hochstein, 1997).

However, the improvement found in texture segmentation tasks might not be due exclusively to perceptual learning as conceptualized by these theories. Our first experiment shows that learning also occurs when no prior information on the texture stimulus (e.g., through extended presentation time) is given. Even when presentation time is set immediately at 33 ms and the stimulus is subsequently masked, participants are able to improve performance on the segmentation task. Experiment 1 thus shows that learning does not need to be enabled by prior stimulus presentation (Ahissar & Hochstein, 1997), and it is not necessary to preactivate features or categories relevant to the segmentation task through practice (Karni & Sagi, 1991). The results of Experiment 2 show that learning is dependent on the masking stimulus. Although the same texture stimuli were used as in Experiment 1, an SPM masked them, and no learning occurred.

Taken together, the results of Experiments 1 and 2 rule out alternative accounts attributing the improvement found in Experiment 1 or the lack of improvement shown in Experiment 2 to specific experimental parameters such as the use of an easily detectable pop-out target (which might have allowed learning in Experiment 1), the short presentation time of the texture stimuli (which might have hindered learning in Experiment 2), or the prolonged training (which might have led to fine-tuning of the sensory channels even without prolonged stimulus presentation and thus allowed learning in Experiment 1). Whereas all of these accounts may explain the results of one of these two experiments, they cannot explain both of them, because none of the parameters just described were changed between the two experiments.

Although these results extend traditional concepts of perceptual learning, they should not be regarded as evidence against earlier findings on this topic. In fact, there is a vast amount of literature documenting both effects of fine-tuning of sensory channels and the influence of top-down activation on perceptual learning. We suggest that, depending on the requirements of the task used in an experiment, different forms of perceptual learning might add to the improvement usually found in perceptual learning tasks. On tasks in which participants are confronted with the identical visual stimulus over many trials, the visual system will exploit the constancy in stimulus material and adapt to the stimuli: Sensory fine-tuning will be observed. In our experiments, however, texture stimuli varied randomly in different aspects from trial to trial: The orientation of the lines forming the texture was swapped, and the target position varied along the horizontal meridian. Adaptation to a specific stimulus would not have been the correct strategy for learning to occur.

The Mask-Ignoring Concept

In the following, we describe a concept that is able to integrate the results of our experiments. Texture segmentation consists of the detection of irregularities in otherwise homogeneous fields. If a texture with such an irregularity is presented, a process is triggered that is specialized in the detection of irregularity. Under natural viewing conditions, this process leads to the automatic detection of the target in the texture stimulus. However, the situation is different in the experimental setting, because the textures are presented only briefly and subsequently masked. Our experiments clearly demonstrate that the mask affects the learning process: Different masks influence performance in different ways. We claim that a heterogeneous mask triggers (as a result of its structure) an irregularity-detection process similar to the one triggered by the texture stimulus. The activation of two similar processes in close temporal order leads to uncertainty regarding the source of activation. In this situation, naive participants show no learning, probably because they cannot discriminate between the two signals.

The situation is different when the texture is followed by a homogeneous mask: A homogeneous mask does not trigger an irregularity-detection process, and no conflict arises in attributing an irregularity signal to the irregularity in the texture stimulus. In this case, learning is possible. The results of Experiment 3 support this idea, because learning was found with a mask that was more complex at the local level than the mask used in Experiment 1 but was homogeneous in terms of its global structure. Furthermore, alongside spatial regularity, temporal regularity (i.e., using the same mask on every trial) can be used during the learning process, as shown in Experiment 4.

Once the separation of the task-relevant irregularity signal (triggered by the texture stimulus) from the irrelevant signal (stemming from the mask) is learned, it can be transferred to situations in which the signals from texture and mask are more similar and separation is initially not possible (e.g., when a heterogeneous mask is used). This was demonstrated in Experiment 5: Participants who had learned to separate the signals with a homogeneous mask (in Experiment 4) were able to transfer this knowledge to a heterogeneous mask (Experiment 5). One could say that they had learned to ignore the mask.

Concepts Regarding Masking

Differences in stimulus perception due to masking stimuli are well known in the literature (see, for overviews, Breitmeyer, 1984; Felsten & Wasserman, 1980; Holender, 1986; Marcel, 1983). Most masking effects result from the mask trailing the stimulus (so-called backward masking). According to Turvey (1973; see, for related concepts, Breitmeyer, 1984; Breitmeyer & Ganz, 1976; Kahneman, 1968), two masking mechanisms can be distinguished when backward masking is considered, namely, integration and interruption. Masking by integration is believed to exert an influence even on the formation of the first representation of the masked stimulus, because the mask is thought to be integrated with the stimulus at a peripheral processing level, resulting in a representation in which the features of the mask merge with the features of the stimulus. In masking by interruption, on the other hand, the mask is considered to not affect the representation of the stimulus but disrupt its further processing, because the mask and the stimulus compete for the same processing resources. Although there is some controversy regarding how the two mechanisms actually work (see, e.g., Coltheart, 1973; Henderson, 1973), evidence has been found for both integrative masking (e.g., Coltheart & Arthur, 1972; Schultz & Eriksen, 1977) and interruptive masking (e.g., Hellige, Walsh, Lawrence, & Prasse, 1979; Spencer & Shuntich, 1970; Turvey, 1973).[5]

At first glance, both masking concepts can account for the results observed. Because of the close temporal order of the texture and the mask, one could consider them to be integrated into a single representation.[6] With a homogeneous mask, this integrated representation would contain only one irregularity (stemming from the target within the texture); conversely, with a heterogeneous mask, the representation would consist of many irregularities. Similar to the mask-ignoring concept, task-relevant irregularity

[5] The mechanisms of interruption and integration have also been applied to other concepts of the processing of stimuli presented in close temporal order, such as in the attentional blink literature (e.g., Giesbrecht & Di Lollo, 1998) and the object substitution concept of Di Lollo and colleagues (Di Lollo, Enns, & Rensink, 2000; Enns & Di Lollo, 1997).

[6] We wish to thank an anonymous reviewer for pointing out this interpretation.

detection would work unambiguously only in the first case. However, this masking-by-integration concept cannot explain the learning transfer found in Experiment 5, in which learning with a homogeneous mask led to expert performance on the part of practiced participants when segmentation had to be performed with a heterogeneous mask. Moreover, performance was already at an expert level in the first block.

The masking-by-interruption concept is more helpful when explaining our data. It suggests that processing of the texture stimulus is disrupted by processing of the mask whenever both processes rely on similar mechanisms. Assuming that the mask interrupts the ongoing processing of the texture stimulus, how can this interruption be overcome, and how is learning to ignore the mask possible?

According to Marcel (1983), masking does not interfere with or terminate stimulus analysis, as stated by most masking theories. Instead, masking occurs because stimulus and mask (as a result of their temporal or spatial proximity) happen to be grouped into the same parsing segment. This notion is based on the assumption that the human information-processing system combines the results of sensory processing into discrete segments, forming a perceptual event available for conscious experience. (In terms of their sensory representation, however, stimulus and mask are not integrated but remain separate. As a result, both stimuli are, in general, available for the processing system.) The human system strives to make sense of the incoming stream of information and thus uses so-called principles to form structured percepts from the elements within a segment. One principle, for example, could be termed the recency principle, according to which the most recent element has privileged access to consciousness.

Marcel's concept allows learning effects to occur. If one assumes that segments can be formed according to the demands of the actual task, participants might have learned to restructure segments in a way that separates the representation of the texture stimulus from the representation of the masking stimulus by assigning each to different episodes. One possible way of doing this is to adjust the temporal borders of a segment by forming shorter temporal episodes. Combined with the mask-ignoring concept, this could account for the differences in learning found with different masks and provide an initial idea of how learning might have occurred.

Conclusion

We conclude by outlining the solution for the contradiction in texture segmentation described at the beginning of this article, namely, its automaticity under "natural" viewing conditions and the need for practice in experimental settings. We believe that texture segmentation is, indeed, an automatic process and that it takes place automatically under experimental constraints. However, participants cannot report the outcome of the segmentation process unless they have learned to ignore the mask. In fact, the only difference between natural texture segmentation and constrained texture segmentation resides in the presence of the masking stimulus in close temporal order. Therefore, it seems appropriate to explain the differences in performance through reference to the mask and its spatial properties. The filtering out of the mask needs to be learned before texture segmentation can be performed in the experimental setting as well. This is the message of the mask-ignoring hypothesis. We do not assume that learning to ignore the mask is the only form of learning that takes place in texture segmentation tasks. However, we wish to point out that the second stimulus and its influence on performance should not be ignored.

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