Attentional Persistence for Features of Hierarchical Patterns

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Priming for perceptual wholes and parts was examined in 4 experiments involving patterns arranged in a spatial hierarchy (D. Navon, 1977). Previous studies have demonstrated "level-specific priming" across successive trials for these patterns (L. C. Robertson, R. Egly, M. R. Lamb, & L. Kerth, 1993; L. M. Ward, 1982), and studies in neuropsychology have shown an absence of this priming effect in patient groups with parietal damage (R. Rafal & L. C. Robertson, 1994). The present experiments demonstrate that level-specific priming is linked to the spatial frequency differences between global and local forms in hierarchical patterns. They also show that level-specific priming is present even when the stimulus as a whole changes location. The effects last for up to 3 s without diminution and are not affected by changes in color, polarity, or contrast. These findings are discussed as they relate to spatial attention, object perception, and memory.

Objects are spatially related in various ways. One object can be next to, behind, or on top of another object. Also, in the natural world, it is common for objects to be parts of larger objects, which in turn can be parts of an even larger object. There are hierarchical spatial relations within visual scenes in which larger sized global shapes encompass smaller sized local shapes. An iris is part of an eye, an eye is part of a face, a face is part of a body, and a body may be part of a crowd. Obviously, an eye differs in shape, size, resolution, and color from the more global object of the face. Any or all of these features can affect attention to and visual processing of the eye. The question addressed in the present study concerned how spatial features are used by the visual system in attending and reattending to where objects exist in a hierarchical structure. I refer to this structure as hierarchical space to reflect the relationship between multiple parts spatially arranged at one level that define a whole object or aggregate at another level.

Global Precedence

Given the prevalence of hierarchical spatial relationships in the natural environment, there has been recurrent interest in how the visual system processes global and local properties of these types of visual stimuli (see Robertson, 1986,

for a historical discussion). Navon (1977) argued that global shapes are processed before local shapes, which led Broadbent (1977) to propose that global shapes are attended to before local shapes. Navon presented hierarchically structured letter and form patterns tachistoscopically and measured response time to identify a global or local shape. Global shapes were identified faster than local shapes and interfered with the identification of local shapes; however, local shapes did not interfere with identification of global shapes. This occurred whether the shapes were letters or forms. On the basis of these two effects, global advantage and global interference, Navon argued that, "all else being equal," the visual system accesses global structure before local structure. The priority in processing time led Navon to propose his theory of global precedence. The findings generated a great deal of discussion over whether global precedence could be attributed to lower order sensory or higher order perceptual and attentional mechanisms (Boer & Keuss, 1982; Broadbent, 1977; Grice, Canham, & Boroughs, 1983; Hoffman, 1980; Kinchla, Solis-Macias, & Hoffman, 1983; Kinchla & Wolfe, 1979; Klein & Berresi, 1985; Lamb & Robertson, 1988, 1989, 1990; Martin, 1979; Miller, 1981; Palmer, 1980; Paquet & Merikle, 1988; Pomerantz, 1983; Ward, 1982).

There was also debate about whether or not the theory of global precedence was correct at all. Kinchla and Wolfe (1979) showed that a global advantage in identification could be changed to a local advantage depending on the overall size of the stimuli. Kimchi and Palmer (1982) demonstrated that the size ratio of global to local forms changed level advantage as well, and Lamb and Robertson (1988) found local precedence effects with central presentation and global precedence effects with peripheral presentation.

After more than a decade of research on global precedence, it is now known that there are several parameters that determine the efficiency of responding to global and local forms defined by levels in a spatial hierarchy. It is also known that several different mechanisms contribute to the overall speed of identification even when all else is equal.

Some component processes that contribute to global precedence respond to attentional manipulations, and others do not (Robertson, Lamb, & Knight, 1988, 1991). Some are involved in interference effects, and others are not (Robertson, Lamb, & Zaidel, 1993). Some are used in early parsing of the stimulus, and others are used in calibrating and maintaining a record of the range of stimulus sizes in a stimulus set (Lamb & Robertson, 1990).

Neuropsychological Contributions

Some of the most convincing evidence for different component processes has been reported in the neuropsychological literature. Damage to different areas of the human brain disrupts different effects (Delis, Robertson, & Efron, 1986; Doyon & Milner, 1991; Lamb, Robertson, & Knight, 1990; Robertson, 1994; Robertson & Delis, 1986; Robertson, Lamb, & Knight, 1988, 1991; Robertson & Lamb, 1991; Robertson, Lamb, et al., 1993). Data from normals involving the use of electrophysiological methods or visual field manipulations have provided converging evidence (Heinze & Munte, 1993; Sergent, 1982). Studies with patients have shown that damage to temporal–parietal regions reveals a hemispheric difference in performance to identify a global or local form. The left hemisphere is normally biased toward local identification and the right toward global identification. Resection of the corpus callosum (so-called "split brain") results in elimination of normal interference effects across levels in the presence of intact global reaction time advantages and the normal direction of hemisphere differences. Damage to parietal lobes disrupts attentional allocation to global and local levels without affecting interference.

The neuropsychological literature also has demonstrated the need for separate attentional mechanisms that can modulate performance for global or local forms (Robertson et al., 1988). One attentional mechanism allocates attention to global or local levels categorically and is disrupted by damage to the inferior parietal lobe (Rafal & Robertson, 1995; Robertson, Lamb, et al., 1993). Other attentional mechanisms adjust the size or attended region of space or what is known as the "attentional window." Regional attention has been associated with a different system in the brain, namely thalamic–cortical interconnections (LaBerge & Brown, 1986, 1989; LaBerge & Buchsbaum, 1990).

Multiple Attentional Mechanisms and Hierarchical Space

Behavioral evidence from young normals supports the idea that both regional and categorical attention contribute to global or local differences in performance when searching for a target in hierarchical space. However, only categorical attention appears to produce lasting effects of selection over trials. Robertson, Egly, Lamb, and Kerth (1993) and Ward (1982) showed that, in healthy undergraduates, attending to a global target improved response time to identify a global target on a subsequent trial and attending to a local target improved response time to identify a local

target on a subsequent trial. There were level-specific priming effects from one trial to the next trial. These effects were not linked to the repetition of the target itself and were later associated with categorical but not regional attention. Robertson, Egly, et al. (1993) showed that attending to a larger or smaller area of geometric space affected performance within a trial but not between trials for hierarchical patterns. Regional adjustments in the size of the attentional window did not produce repetition priming, whereas categorical attention to the target level did affect priming. The level of the target was irrelevant for the response, yet it still produced reliable priming.

Other investigators have also reported response-irrelevant priming, but from features of color and location. Maljkovic and Nakayama (1994) used visual search displays that produce "pop out." They reported a buildup of priming over several trials in an odd-one-out task when the target remained the same color across trials. This occurred whether or not the target form, overt response, or location changed across trials. They also demonstrated a similar effect for location. When the odd-one-out target appeared in the same location across trials, priming occurred whether or not the form, response, or color changed. These data also are consistent with Muller, Heller, and Ziegler's (1995) conclusions that pop out does not require knowledge of the particular features in the odd-one-out task but does require knowledge of the particular dimension of the target. Muller et al. found that trial-by-trial priming occurred for targets within the same dimension but not for targets that crossed dimensions. Both they and Wolfe (1994) have suggested that weights assigned to features on trial $N - 1$ carry over to the next trial to create costs and benefits.

Hierarchical stimuli are not multiple forms scattered across space, as in visual search displays, but they can be conceptualized as multiple forms appearing across hierarchical space. There are levels of object structure that vary in resolution. Visual search may progress through these levels of resolution during searches for a target. Global precedence theory proposes that this search begins at the global level. However, the presence of level-specific priming questions this proposition. Where search begins in hierarchical space can be influenced by where a target was found in the hierarchy on the previous trial.

In the present set of studies, response-irrelevant priming effects were explored further through the use of hierarchical patterns. Consistent with previous findings, the data demonstrate that level-specific priming effects occur whether or not the identity or shape of the target changes. It is shown here that these priming effects remain strong and unchanged over a 3-s intertrial interval (ITI). They do not decay as would be predicted by a sensory account. Furthermore, it was found that level-specific priming is of nearly equal magnitude whether there is an overall local or global advantage in reaction time and is equally strong for global and local responses. Most important, level-specific priming was found to be linked to the spatial frequency value of the target on the previous trial. When spatial frequency differences between levels were eliminated while retaining the levels of structure, level-specific priming disappeared.

Finally, the concept of an "attentional print" is introduced here to account for the repetition effects of spatial features. In hierarchically arranged stimuli, these effects are level specific but response and shape nonspecific. In pop out displays, the effects can be color or location specific but response and shape nonspecific. The attentional print refers to a trace of the features that guide parsing of the visual field into candidate channels for selection. In selecting a global or local target in a hierarchical pattern, the print contains a record of the attentional weights associated with the use of spatial frequency values in selection. One intriguing aspect of this print is that it need not contain a record of the target shape itself, the location of the target in metric space, or the response decision made on the previous trial. The trace is more abstract than has been generally proposed to account for perceptual priming. In essence, the attentional print contains a record of how features were used during selection. This record is reactivated when a stimulus with similar spatial organization appears again. A more thorough discussion of the model follows data presentation.

Experiment 1

Experiment 1 was designed to evaluate the effect of location changes between trials on level-specific priming. On each trial, a hierarchical pattern was presented for 100 ms either to the left or right of fixation. Each stimulus was a global letter created from multiple local letters, as shown in Figure 1. Participants were given a target set of two letters before testing began, and each trial contained one of the two targets either at the global or local level but never at both. Participants pressed a key to judge which target was present on each trial regardless of target level. Each trial ended with a response, and a new pattern was presented 1.5
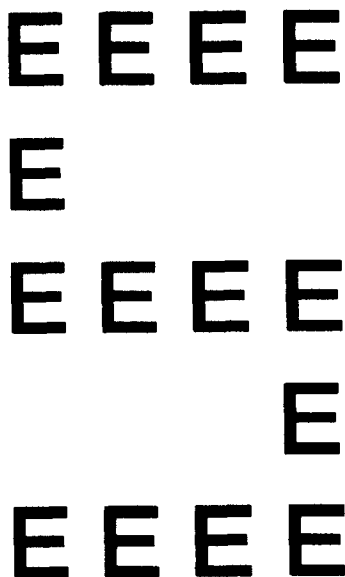

Figure 1. Example of a global letter created from the repetition of local letters.

s later either in the same location on the screen or in a different location. The target level (global or local) was either the same or different, and the target letter was either the same or different. In this way, the contribution of level-specific priming could be evaluated separately from target letter priming.

Method

Participants. Fifteen participants were recruited from Saint Mary's and Mount Diablo community colleges in Walnut Creek, California, and paid for their travel and participation. They were tested at the Veterans Administration facility in Martinez, California. All participants were right-handed. All gave informed consent before participation.

Apparatus. Stimuli were generated on an NEC-3D MultiSync Color Monitor (NEC Technologies Inc., Boxboro, Massachusetts) controlled by a 486 IBM-AT-compatible computer with an ATI-VGA Wonder Graphics card (International Business Machines, Armonk, New York). Stimulus timing (onset, offset, and duration) was tied to the vertical sync pulse. All other timed events (reaction times and ITIs) were timed by an 8253 chip set to a 1-ms base. Status of the response key was monitored by the game port. A standard response box was used for push button responses.

Stimuli. Patterns were created by placing local letters in a 5 × 4 matrix to produce a global letter. The letters were blocked forms of H, S, E, and A. H and S were designated as targets, and each stimulus contained an H or an S as target and an E or an A as distractors; however, no stimulus contained global and local targets or global and local distractors. This procedure resulted in eight patterns that were randomly presented in a block of 256 trials. The global letters were 46.8 mm high and subtended a visual angle of approximately 5°; the local letters were 7.8 mm high and subtended about 0.8°. A small plus sign about 0.1° in visual angle was used as a fixation point.

Procedure. Participants were seated 54 cm in front of the display screen with their chin resting in a headrest. Each trial began with a 500-ms fixation point in the middle of the screen. Immediately after offset, a hierarchical pattern appeared and was displayed for 100 ms 4° to either the right or the left of fixation. Presentation time was limited to prevent saccadic eye movements. Participants were instructed to focus on the fixation point when it appeared and to keep their eyes in the center throughout the trial. They were told to press the right-sided switch on a response box if the target was an H and the left-sided switch if the target was an S. Half of the participants used the index and middle fingers of their left hand to make responses, and half used the index and middle fingers of their right hand. One second after the participant's response, the next trial began. Stimulus files were structured to produce equal numbers of pairs that had the same or different target letter, same or different target level, and same or different location.

Results

The data were analyzed in a 2 × 2 × 2 analysis of variance (ANOVA) for repeated measures. The variables were target level repetition (same level vs. different level), stimulus location repetition (same location vs. different location), and target letter repetition (same letter vs. different letter), which was also the same or different keypress. Each cell was defined as a function of the level, letter, and

location of the target on the previous trial. Mean response-times for each participant were calculated for each cell of the design.[1] Only correct responses were included.

Level-specific repetition effects. Level-specific priming was observed. There was a main effect of level repetition, $F(1, 14) = 29.07, p < .001, MSE = 1,008$. Response times were 32 ms faster for same-level than for different-level conditions. Level repetition did not interact with either letter repetition or location repetition (see Table 1).

Simple comparisons showed that the level repetition effects were present for same-location and different-location conditions. There were level repetition effects of 30 ms when the location changed, $F(1, 14) = 20.41, p < .001, MSE = 337$, and 32 ms when the location remained the same, $F(1, 14) = 16.40, p < .001, MSE = 473$. The interaction between level repetition and location repetition did not reach significance.

Level-specific priming also was present whether target letter (and thus response key) changed or not. Simple comparisons showed that the level repetition effects were present for same-letter and different-letter conditions. There were level repetition effects of 21 ms when the target changed, $F(1, 14) = 10.99, p < .01, MSE = 324$, and 41 ms when the target remained the same, $F(1, 14) = 23.21, p < .001, MSE = 535$. The interaction between level repetition and letter repetition did not reach significance (see Figure 2).

Unexpectedly, there was a highly reliable interaction between letter repetition and location repetition, $F(1, 14) = 85.06, p < .001, MSE = 734$. Simple comparisons were made to determine the source of this interaction. These comparisons demonstrated that when the hierarchical stimulus appeared in the same location on successive trials, a different target letter slowed reaction time by 45 ms relative to the same target letter, $F(1, 14) = 42.26, p < .001, MSE = 354$; when the stimuli appeared in different locations, however, reaction time to a different target letter was 46 ms faster than to the same target letter, $F(1, 14) = 31.64, p < .001, MSE = 515$. In other words, a change in location or a change in target produced slower response times (611 ms and 615 ms) than when either both location and target remained the same or both changed (565 ms and 570 ms). It is important to note that these effects did not interact with

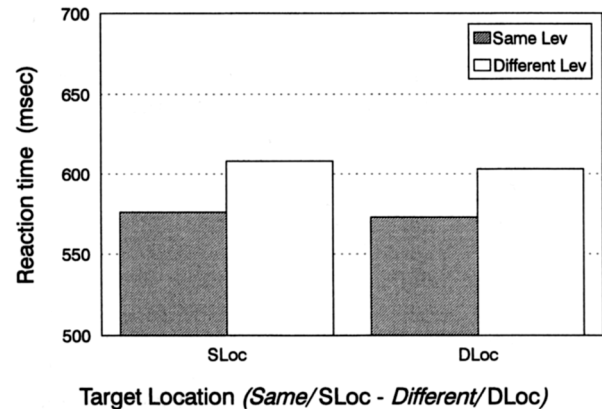Target Location *(Same/*SLoc - *Different/*DLoc*)*

Figure 2. Mean reaction time for repetitions of stimulus location (SLoc = same location, DLoc = different location) and target level (Lev) across trial pairs. Data are collapsed over global and local targets.

level repetition, $F < 1$. No other effects were significant in the initial analysis.[2,3]

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[1] In a previous version of this article, I reported medians rather than means. To conform to the analyses of similar effects reported in the literature, I report means rather than medians in the text here. The only difference in the results between using medians and means was that letter repetition had no effect on level repetition when medians were analyzed but showed a small reduction in level repetition effects for the means as reported in the text. Level repetition was strong with medians, $F(1, 14) = 18.37, p < .001, MSE = 1,456$, and there was no interaction between level repetition and letter repetition in either case. All other effects were similar for medians and means.

[2] A second potential source of letter-specific effects was the distractor or the nontarget letter (Tipper, 1985). This letter also remained the same or changed across trials orthogonal to changes in the target letter. As a means of determining whether or not distractor letter changes interacted with target level or location changes, a Target Location (same vs. different) × Distractor Letter (same vs. different) × Target Level (same vs. different) analysis was performed. Data were collapsed over target letter to ensure adequate power to perform this analysis. Overall reaction time was the same whether the distractor letter remained the same or differed (590 vs. 589 ms). Distractor letter repetition did not interact with target level repetition or location repetition. Furthermore, there was no Distractor Letter × Target Level × Location interaction. The level repetition effects were 29 ms when the distractor letter was different, $F(1, 14) = 23.73, p < .001, MSE = 317$, and 25 ms when the distractor was the same, $F(1, 14) = 12.80, p < .01, MSE = 313$. Inhibition of the distractor letter could not account for level-specific priming.

[3] Theories of perceptual priming are often based on hypersensitivity to parameters of a specific object (Tulving & Schacter, 1990). Such theories predict that priming would be observed when the distractor and target were the same across trials (e.g., a global H with local Es followed by a global H with local Es). Priming should be present (or greater) when both global and local patterns remain the same but absent (or reduced) when the distractor or target changes. As a means of testing this prediction, individual comparisons were made for the four different types of prime-target pairs (see Table 11 for the means and level repetition effects

Table 1
Experiment 1: Analysis of Variance Results

Source	MSE	$F(1, 14)$	p
Prime–probe target letter (same–different)	1,003	0.03	.863
Prime–probe target level (same–different)	1,008	29.08	.001*
Letter × Level	712	3.77	.070
Stimulus field (same–different)	431	1.32	.270
Letter × Field	734	85.06	.001*
Level × Field	615	0.04	.834
Letter × Letter × Field	759	0.07	.785

* $p < .05$.

Global and local priming effects. As a means of verifying that switching from one target level to another target level between trials was similar for both global-to-local and local-to-global changes across trials, a 2 × 2 planned analysis was performed. This analysis included the target level probe on trial *N* (global or local) as a function of target level prime on trial *N* − 1 (global or local). The data are shown in Figure 3.

There was a significant main effect of level for the probe on trial *N*, $F(1, 14) = 35.52, p < .001, MSE = 2,122$, and a significant interaction between prime and probe target level, $F(1, 14) = 24.43, p < .001, MSE = 544$. The overall level advantage favored global targets by 71 ms, consistent with previous studies using parafoveal presentation (Lamb & Robertson, 1988; Navon, 1977). Planned comparisons showed that response times to global targets on trial *N* preceded by global targets on trial *N* − 1 (gG in Figure 3) were faster than those preceded by local targets (lG in Figure 3) by an average of 35 ms, $F(1, 14) = 38.12, p < .001, MSE = 233$, and response times to local targets on trial *N* preceded by local targets on trial *N* − 1 (lL in Figure 3) were faster than those preceded by global (gL in Figure 3) targets by an average of 23 ms, $F(1, 14) = 7.03, p < .02, MSE = 672$. Level-specific priming was evident for both global and local levels.

Errors. The overall mean error rate was 7.3%. Error data were analyzed in the same 2 × 2 × 2 design as reaction time for the initial analysis. The variables were level repetition (same level vs. different level), location repetition (same location vs. different location), and letter repetition (same letter vs. different letter). The only significant effect was a Letter Repetition × Location Repetition interaction, $F(1, 14) = 9.92, p < .01, MSE = 0.003$, similar to that found in the reaction time data.

It is important to note that errors did not show evidence of level-specific priming. The error rates were 7.2% when targets were at the same level across trials and 7.4% when targets changed levels between trials. Level-specific priming appears to reflect the speed of processing but not the final percept.

Discussion

The results of Experiment 1 demonstrated a level-specific priming effect across changes in location and changes in target letter. Responses were slow when the target level switched from global to local or local to global levels across successive trials as compared with when the target level

Figure 3. Mean reaction time for global and local targets on trial *N* as a function of the target level on the previous trial (*N* − 1). The lowercase letters (g and l) refer to the global or local target level on the previous trial, and the uppercase letters (G and L) refer to the global or local target level for the response times shown. D - Level = different level; S - Level = same level.

remained the same. These level-specific priming effects were present both when the target letter changed and when the location of the stimulus as a whole changed. Level-specific priming was found, as was the case in the studies of both Ward (1982) and Robertson, Egly, et al. (1993).

The level of the target on the preceding trial affected performance on the next trial even though level was response irrelevant (i.e., equally probable and irrelevant to the response of H or S). Participants were not required to report the level of the target, rather, they were required to report only which target occurred. Some dimension or feature that could be used in selectively attending to the correct target level on the previous trial influenced the speed of target selection on the next trial. These effects occurred whether or not the identity and location of the previous target changed and were found only in the reaction time data. Accuracy of response did not show level-specific priming.
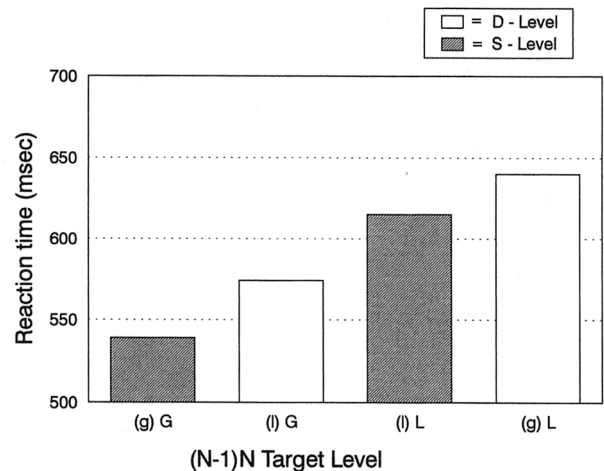
It was assumed that if the target letter on any trial was to be determined, parsing the stimulus into global and local levels had to occur with selection of a candidate level strengthening over time. However, neither the semantics of the letter nor its shape could account for level-specific priming. Whether the same global–local pattern was presented on trials *N* − 1 and *N* or different global–local patterns were presented, level-specific priming resulted.

It is reasonable to assume that parsing of global and local levels takes place at a relatively early stage of visual processing (preattentively). One feature that has been associated with global–local processing that could be used to parse the two levels is spatial frequency. This would result in two major channels for further inspection: a relatively low-frequency stream more closely associated with the fundamental frequency of the global level and a relatively high-frequency stream more closely associated with the

for all four combinations). In every case but one, the level repetition effect was significant. For same letter–same distractor, the effect was 31 ms, $F(1, 14) = 11.23, p < .01, MSE = 620$. For same letter–different distractor, the effect was 44 ms (if anything, greater), $F(1, 14) = 20.34, p < .01, MSE = 710$. For different letter–same distractor, the effect was 6 ms, but this effect was not significantly different. For different letter–different distractor, the effect was 28 ms, $F(1, 14) = 8.46, p < .02, MSE = 687$. The one case that did not reach significance here did reach significance levels in the remaining studies in which priming was observed.

local level. Level-specific priming appears to be due to attentional allocation to these streams before the target form or its identity is fully known. Attentional weights would be assigned to each stream and then be changed via feedback or clues as to which stream is more likely to resolve the target. For instance, a stream may have emerging evidence of a probable H or S form (as opposed to an E or A form) in a given channel before the specific identity of the target H or S is known. A schematic of how this could occur is presented in Figure 4. After sensory registration, which includes the spectrum of spatial frequencies in the stimulus, parsing occurs by selective filtering of the raw frequency information into streams with larger and smaller resolution designated as "blobs." Attentional weights are assigned during the early filtering processes and through some of the later stages. The shape itself is represented in memory as size invariant, leaving the attentional weights assigned primarily to the global and local blobs. This model, which was supported by the data from the remaining experiments, is more fully discussed as those data are presented.

A strong relationship between global targets and low frequency on the one hand and between local targets and high spatial frequency on the other already has been established in the literature (Hughes, Fendrich, & Reuter-Lorenz, 1990; LaGasse, 1993; Shulman, Sullivan, Gish, & Sakoda, 1986). In addition, Shulman and Wilson (1987) demonstrated that attending to a global target increased detection of low-frequency sine wave gratings, whereas attending to a local target increased detection for high-frequency gratings. The influence of spatial frequency in the level-specific priming effects found in Experiment 1 was demonstrated in Experiment 3. For now, it is important only to note that some response-irrelevant feature that differentiates global from local levels influenced performance on a subsequent trial. Because level-specific priming occurred both when the target shape changed and when it did not, the data support the existence of a shape-independent trace that contributed to the priming effects observed here.

Experiment 2

The stimuli in Experiment 1 were all presented in peripheral vision, where global precedence effects are most often observed. As a result, reaction times for global targets were, overall, faster than reaction times for local targets in Experiment 1. Global or local reaction time advantage is greatly affected by where the patterns are presented relative to fixation. Whereas global advantages are more likely with parafoveal presentation, local advantages are more likely when stimuli are presented at central fixation (Lamb & Robertson, 1988). In Experiment 1, a reaction time advantage for global targets was observed, as expected, because stimuli were presented parafoveally. Because level-specific priming effects occurred whether or not the stimulus location changed and are argued to be independent of sensory persistence, they should be observed even with central presentation that eliminates or reverses the global processing priority.

Experiment 2 also was designed to explore the effects of ITI on level-specific priming. How long do the effects last? Experiment 2 was similar to Experiment 1 except that all stimuli were presented in the center of the screen and the ITI was 1, 2, or 3 s. ITI duration varied randomly from trial to trial. If sensory persistence were present (as opposed to a trace that reactivates feature weights), some diminution of level-specific priming would be expected over the 3-s interval. Although longer intervals could have been selected, they would have increased the testing time accordingly, and 3 s should be sufficient to assess the role of sensory persistence.

Method

Participants. Twelve new participants, recruited from the undergraduate student population at the University of California, Davis, were paid to take part in Experiment 2. All participants were tested at the Center for Neuroscience in Davis. All gave informed consent before participation.

Procedure. The procedure was the same as that of Experiment 1, except that location variations were excluded and all stimuli were presented in the center of the screen with variable ITIs between N and $N - 1$. Stimuli were presented for 100 ms as before, and the trial ended when the participant responded. After the response, there was an ITI of 1 s (as in Experiment 1) or an ITI of 2 or 3 s before the next trial began.

Results

ANOVAs for mean response times were calculated for each cell of the design for each participant. The initial analysis was a $2 \times 2 \times 3$ factorial with level repetition (same level vs. different level), letter repetition (same letter vs. different letter), and ITI (1,000 vs. 2,000 vs. 3,000 ms) as within-subject variables. Only correct responses were included.

Level repetition produced a significant main effect, $F(1, 11) = 16.43, p < .01, MSE = 4,766$. Reaction times for targets at the same level across trials were 47 ms faster than reaction times for targets that changed levels (see Table 2).

There was also a main effect of letter repetition, $F(1, 11) = 11.62, p < .01, MSE = 4,304$. However, it was in the opposite direction for a target letter priming effect. Response times were 37 ms faster for different letters than for same letters. Unlike in Experiment 1, in which a possible trend in the pattern of means was observed between letter repetition and level repetition, Experiment 2 revealed a significant Letter Repetition × Level Repetition interaction, $F(1, 11) = 5.67, p < .04, MSE = 2,156$. However, simple comparisons demonstrated level-specific priming whether the target changed or not. When the target was the same letter across trials, response times were 65 ms slower when the target level changed than when it remained the same, $F(1, 11) = 12.47, p < .01, MSE = 2,035$. When the target letter was different across trials, response times were 28 ms slower when the target level changed than when it remained the same, $F(1, 11) = 17.57, p < .01, MSE = 271$. Thus,
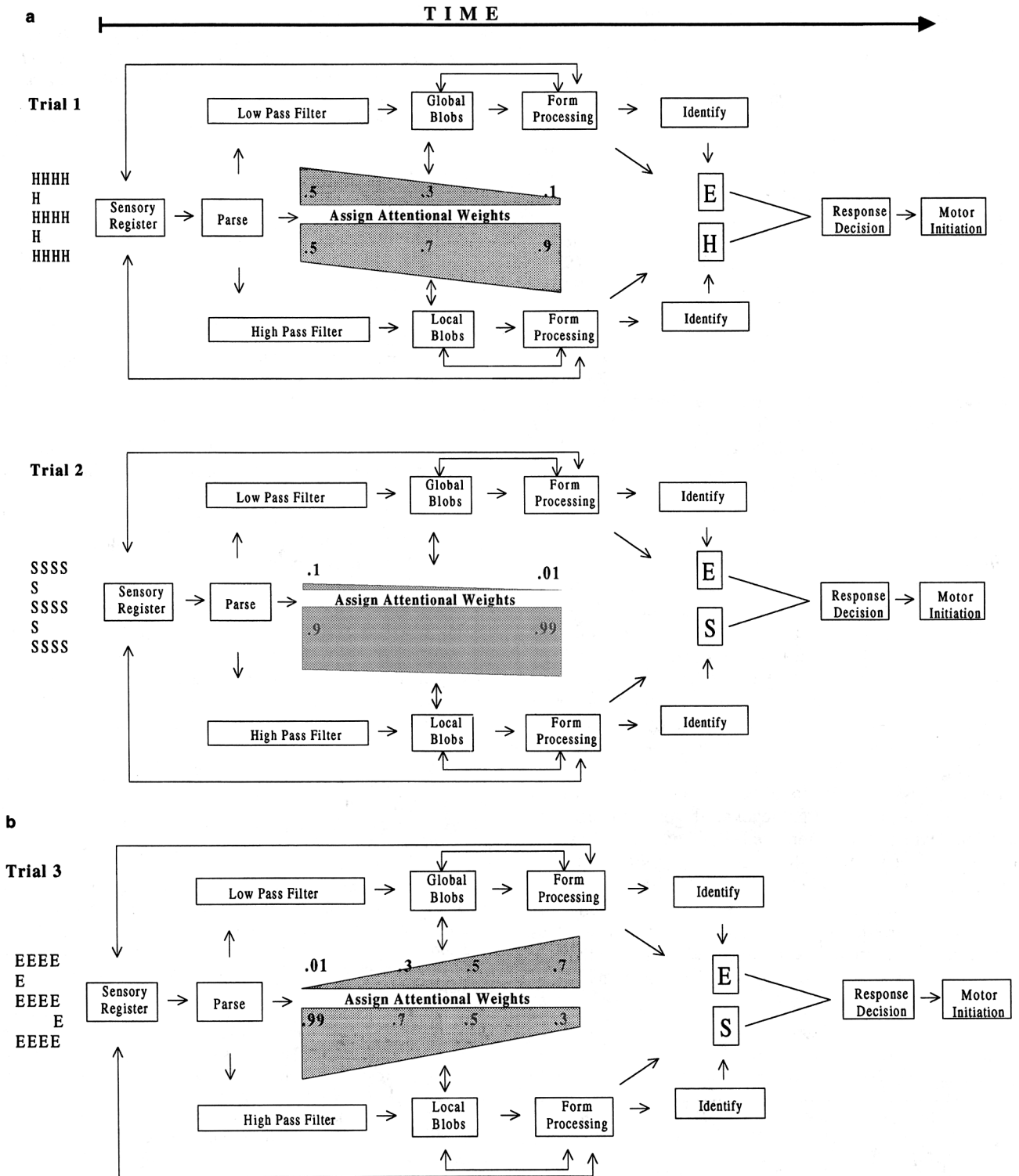
Figure 4. Examples of the model on given trial sequences. The participants' task was to indicate whether an H or an S occurred on each trial. On Trial 1, there had been no previous stimulus and, thus, no previous act of selection or assigning of attentional weights. Assignment of attentional weights begins unbiased for simplicity. On Trial 2, assignment of weights is as they ended on Trial 1. The target was at the same level, and response occurred rapidly. On Trial 3, assignment of weights is as they ended on Trial 2. The target was at a different level, and response occurred more slowly (see text for full discussion).

whether or not the target letter changed, significant level priming was observed as in Experiment 1.[4]

There was no evidence that level-specific priming effects changed across ITIs, $F < 1$. However, letter repetition effects did interact with ITI, $F(1, 11) = 6.22, p < .03, MSE = 2,120$. No other effects reached significance.[5]

Effects of ITI. As just noted, ITI interacted with letter repetition but not with level repetition. Simple comparisons showed that letter repetition effects decreased over ITIs, whereas level repetition effects did not. Response times were 70 ms longer for same letters than for different letters at the 1,000-ms ITI, $F(1, 11) = 15.92, p < .01, MSE = 1,840$. This difference was reduced to 26 ms at the 2,000-ms ITI, $F(1, 11) = 3.74, ns, MSE = 1,110$, and 16 ms at the 3,000-ms ITI, $F(1, 11) = 1.86, ns, MSE = 1,321$.

In contrast to the effect of ITI on target letter repetition, there was no effect of ITI on level repetition. Response times were 42 ms faster for same-level than for different-level targets at the 1,000-ms ITI, $F(1, 11) = 4.82, p < .05, MSE = 2,185$; 50 ms faster at the 2,000-ms ITI, $F(1, 11) = 13.57, p < .01, MSE = 1,114$; and 48 ms faster at the 3,000-ms ITI, $F(1, 11) = 11.78, p < .01, MSE = 868$. The variability decreased over ITIs, but the magnitude of the level repetition effects remained unchanged (see Table 3).

Global and local priming effects. As in Experiment 1, a second planned analysis was performed to evaluate whether the global or local target repetitions differed in terms of level-specific priming effects. This question was evaluated in a 2 × 2 × 3 ANOVA for repeated measures; probe level on trial N (global vs. local) was one variable, and prime level on trial $N - 1$ (global vs. local) was another. ITI was also included in this analysis; the purpose of introducing a variable ITI was to evaluate its effects on level repetition priming.

Consistent with the results of Experiment 1, there was an interaction between the target level on the previous trial and the target level on the current trial (i.e., level-specific priming was evident for both global and local responses), $F(1, 11) = 18.23, p < .01, MSE = 4,459$. Response times for global probes on trial N were slower by 38 ms when these probes were preceded by a local prime on trial $N - 1$ as compared with when they were preceded by a global prime, $F(1, 11) = 7.55, p < .02, MSE = 1,115$, and response times

Table 2
Experiment 2: Analysis of Variance Results

Source	MSE	F(1, 11)	p
Prime–probe target letter (same–different)	4,304	11.62	.006*
Prime–probe target level (same–different)	4,766	16.43	.002*
Letter × Level	2,156	5.67	.035*
ITI (1, 2, or 3 s)	3,621	2.81	.081
Letter × ITI	2,120	4.52	.022*
Level × ITI	1,785	0.12	.885
Letter × Letter × ITI	1,620	0.25	.787

Note. ITI = intertrial interval.
* $p < .05$.

Table 3
Experiment 2: Mean Reaction Times (Milliseconds) for Intertrial Intervals (ITIs) of 1, 2, and 3 s When Targets on N − 1 and N Were the Same or Different Letter or Same or Different Level

	ITI (in seconds)		
Target	1	2	3
Letter			
Same	639	605	629
Different	569	579	613
Difference	70*	26	16
Level			
Same	583	567	597
Different	625	617	645
Difference	42*	50*	48*

Note. Letter priming was affected by ITI; level priming was not.
* $p < .05$.

for local probes on trial N were slower by 58 ms when such probes were preceded by a global prime on trial $N - 1$ as compared with when they were preceded by a local prime, $F(1, 11) = 27.34, p < .001, MSE = 727$. The data for each ITI are shown in Figure 5. Level-specific repetition effects for global and local levels were not differentially affected by ITI. They remained strong for at least 3 s with no evidence of reduction in strength.

Global–local response time advantage. The predicted main effect of an overall response time advantage for local targets with central presentation was not the same across the three ITIs. There was a significant 41-ms local advantage at the 1,000-ms ITI (the ITI used in Experiment 1), $F(1, 11) =$

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[4] Mean response times were 592 ms for same level–same letter and 573 ms for same level–different letter. This was not a significant difference. Mean response times were 601 ms for different level–different letter and 657 for different level–same letter. This difference was significant, $F(1, 11) = 14.60, p < .01, MSE = 1,274$. In other words, a slower response time to the same letter occurred only when the target level changed. Although it is difficult to know the meaning of a slower response to the same target, it could not account for level-specific priming effects. Level-specific priming was found whether or not the target letter changed.

[5] As in Experiment 1, distractor effects were also examined. The sequential effects could not be attributed to active inhibition of the identity of the distractor. There was no evidence of any sequential effects due to distractor letter similarities across trials. As in Experiment 1, the Target Letter × Distractor Letter × Target Level interaction was not significant, $F < 1$. Finally, repeating the same stimulus (with both global and local levels the same) produced level-specific priming, and such priming was also observed under conditions in which the target remained the same and the distractor changed, as well as under conditions in which the target changed but the distractor remained the same (see Table 11 for the means of the different target and distractor combinations for each level repetition condition). Significant level repetition effects were found for same target–same distractor, $F(1, 11) = 32.56, p < .001, MSE = 1,166$; same target–different distractor, $F(1, 11) = 6.34, p < .03, MSE = 3,859$; and different target–same distractor, $F(1, 11) = 21.92, p < .001, MSE = 460$.
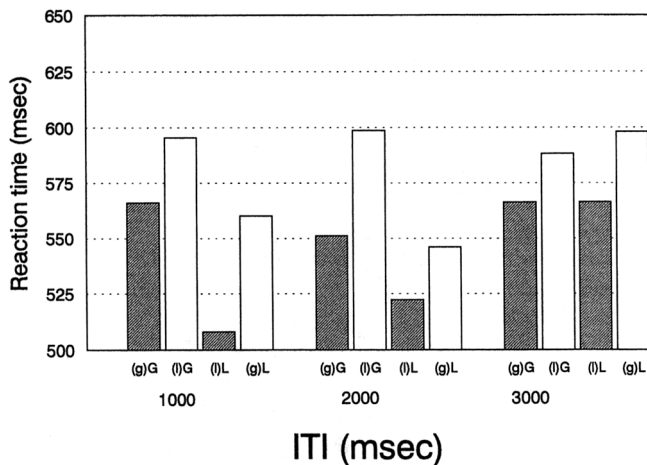
Figure 5. Mean reaction time for global and local targets on trial *N* as a function of the target level on the previous trial *N* − 1 for intertrial intervals (ITIs) of 1,000, 2,000 and 3,000 ms. The lowercase letters (g and l) refer to the global or local target level on the previous trial, and the uppercase letters (G and L) refer to the global or local target level for the response times shown.

5.50, *p* < .04, *MSE* = 1,837. In contrast, a 40-ms local advantage at the 2,000-ms ITI did not reach significance (*p* < .12), and this effect all but vanished at the 3,000-ms ITI (4-ms difference).

This finding may mean that a local advantage for centrally presented stimuli reflects some controlled attentional process in defining the size of an attentional window over time (Eriksen & St. James, 1986; Eriksen & Yeh, 1985; LaBerge & Brown, 1986; Robertson, Egly, et al., 1993). As noted in the introduction, these effects have not shown priming (Robertson, Egly, et al., 1993). Whatever the case, this finding, in combination with those of Experiment 1, demonstrates that level-specific repetition effects occur whether there is an overall global or local advantage (see supporting evidence from Kim, 1994).

Errors. The same 2 × 2 × 3 design used in the initial analysis of reaction time was used to analyze error data. The overall error rate was 2.9%. The only significant effect was a main effect of ITI, $F(2, 22) = 6.08$, *p* < .01, *MSE* = 0.003. Errors decreased over ITIs from 5.3% at 1 s to 1.6% at 3 s. Overall error rates were 2.6% for the same-level condition and 3.2% for the different-level condition. This was not a significant effect. As in Experiment 1, level-specific priming was found in timing measures but not in accuracy.

Discussion

The data from Experiment 2, in which central presentation was used, replicated the level-specific priming found in Experiment 1 with peripheral presentation. When the target level changed between trials, reaction time was slower than when the target level remained the same. Global targets preceded by global targets were identified more rapidly than

global targets preceded by local targets, and local targets preceded by local targets were identified more rapidly than local targets preceded by global targets. The magnitude of level-specific priming remained virtually the same for at least 3 s without change. ITIs beyond this duration were not sampled, so it is not known how long the effects would have lasted; however, there was no evidence that they were diminished between 1 and 3 s.

Letter repetition effects were also evident in Experiment 2, as they were in Experiment 1 when patterns were located at the same location either to the right or left of fixation on successive trials. Given that all patterns were shown in the center of the screen in Experiment 2, letter repetition effects were not particularly surprising. What is surprising is the direction of the effect. When the same target letter occurred, response time was slower than when different target letters occurred. These effects were found only at the 1-s ITI; they were completely absent by 3 s. Unlike the level priming effects, letter repetition effects decayed over the 3-s interval.

Although it is not clear why a different target would produce faster response times than the same target, there was statistical evidence in both Experiments 1 and 2 that level repetition effects were present for both same-letter and different-letter conditions. Whereas ITI did not affect the magnitude of the level repetition effect, letter repetition effects were reliable at the 1-s ITI but had all but vanished by the 3-s ITI. These differences provide converging support for a separation between level priming and identity priming.

Finally, the results of Experiments 1 and 2 together showed that central and peripheral presentation produced a difference in overall reaction time advantage in identifying global or local forms. In Experiment 1, in which patterns were shown parafoveally, there was an overall global advantage of nearly 80 ms; in Experiment 2, in which patterns were shown centrally, there was an overall local advantage of 40 ms at the 1-s ITI, the ITI common to both experiments. This difference in local or global advantage in central versus peripheral presentation replicates those found by Lamb and Robertson (1988).

More important for the present purposes, level-specific priming effects were present and reliable whether a global or local reaction time advantage was present. Response times to targets at the same level on successive trials were faster than response times to targets at different levels on successive trials under both conditions. An increase in reaction time due to a change in target level between trials occurred in both experiments. In other words, the overall global or local advantage observed across experiments could be attributed to sensory factors, but level advantage was independent of level-specific priming effects and must reflect a higher order process.

Experiment 3

The data from Experiments 1 and 2 demonstrated that a change in target level on successive trials slowed reaction

time whether that change was from local to global targets or from global to local targets. These level-specific priming effects could not be attributed to target letter repetition or response repetition. Level-specific priming effects were unaffected by duration of ITI. The findings so far demonstrate that level-specific priming occurred whether the stimulus patterns on successive trials were in the same or different locations (Experiment 1), whether they were presented in central vision (producing a local advantage, at least at the 1-s ITI) or in peripheral vision (producing a global advantage), and whether or not the target letter (and thus the response) changed. Level-specific priming was also present whether the interval between trials was 1, 2, or 3 s and showed no indication of reduction over ITI duration (Experiment 2).

These findings replicate and extend those of previous reports involving hierarchical stimuli (Robertson, Egly, et al., 1993; Ward, 1982). However, they do not address issues about what features of global and local forms or what processing mechanisms contribute to these effects. The previous experiments showed that whatever features produce level priming, they do so whether the location of the whole pattern changes or not and whether the target form changes or not. These features were not integrally linked to the target letter itself or the stimulus location. Yet they were sufficient to differentiate global from local levels so as to influence performance on a subsequent trial in a level-specific manner. Spatial frequency is one candidate feature that is consistent with the fact that a location change did not eliminate level priming. Spatial frequency can be represented independent of locations in space (DeValois & DeValois, 1988), and parsing by spatial frequency can occur independent of and before form identification (Watt, 1988).

The model shown in Figure 4 predicts that level-specific repetition effects will be eliminated if parsing on the basis of spatial frequency cannot occur. As a means of testing this hypothesis, hierarchical patterns with global and local letters were used in Experiment 3 (see Figure 6), but lower spatial frequencies (below three cycles per degree) were removed by contrast balancing procedures. Low or high pass filtering in traditional ways was not appropriate because this procedure can disrupt the percept that the stimulus is a hierarchical pattern and would have confounded level with frequency. The perceived global–local structure of the pattern would change. Contrast-balanced (CB) patterns do not confound level with spatial frequency.

Hughes et al. (1990) circumvented the problem of disrupting hierarchical spatial structure by constructing global–local figures from CB dots. This procedure eliminates the lower frequency energy in the stimulus without eliminating the hierarchical structure (see Figure 6). Under these conditions, Hughes et al. found that global precedence in reaction time was eliminated. These types of patterns were used in Experiment 3. Spatial filtering would not result in two processing streams associated with global and local levels. Rather, the percept of both local and global forms could rely only on higher frequency information. Processes different from those used in the typical broadband, "dark" stimulus would have to be used to resolve the pattern.
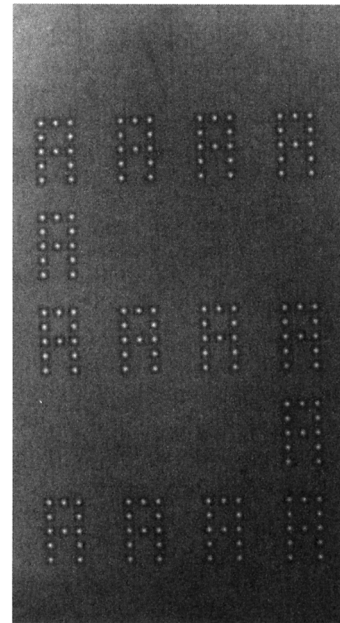

Figure 6. Example of a hierarchical letter created from contrast-balanced dots. The figure is a photograph and only approximates the pattern on the monitor.

In Experiment 3, trials with hierarchical patterns created from CB dots alternated with trials containing high-contrast patterns (dark) constructed exactly like those in Experiment 2. Note that the size and hierarchical structure of the patterns were the same in CB and dark stimuli. The question was whether or not level-specific priming effects would be observed when the dark patterns were preceded by CB patterns. If the spatial frequencies used to selectively attend to a target level on the previous trial contributed to the level-specific priming found in Experiments 1 and 2, then level priming should be substantially reduced or eliminated entirely in Experiment 3. Attentional weights cannot be assigned to different frequencies in a CB stimulus because the frequencies do not differentiate the two levels; thus, these attentional weights could not influence performance on a subsequent trial. Likewise, the attentional weights in a preceding dark pattern would not be functional when confronted with a CB pattern. Parsing on the basis of spatial frequency cannot occur in the latter, and the attentional weights of the last trial could not be assigned. Again, this model does not predict that spatial frequency values themselves persist. Rather, it proposes that the interaction between spatial frequencies used to parse a stimulus and attentional weights assigned to processing streams that result from this parsing leaves a trace. If spatial frequency stimulation itself were sufficient to produce level-specific priming, then a dark local target on trial $N - 1$ should produce facilitation for all CB targets on trial N because both global and local targets contain only high spatial frequency energy. However, if the representation that persists involves the attentional weights assigned to spatially filtered channels, the level priming effect should not appear.

Finally, the design of Experiment 3 also included manipulations of the probability of a global or local dark stimulus (e.g., the typical broadband pattern used in the previous two experiments) to address questions concerning attentional control over level priming effects. Can attention be reallocated in a controlled fashion when the participant expects a global (low-frequency) target in an upcoming dark pattern after responding to a high-frequency CB pattern? In other words, are level priming effects driven by bottom-up or top-down processing?

Method

Participants. Sixteen new participants were recruited from a local community college to take part in Experiment 3. Testing was performed at the Veterans Administration facility in Martinez, California. All participants were between the ages of 19 and 22 years and had normal or corrected-to-normal vision. All gave informed consent before beginning the experimental session.

Stimuli. The dark stimuli were the same as in Experiments 1 and 2. CB stimuli were constructed with dots created by increasing the luminance of a central pixel in a 3 × 3 matrix and decreasing the luminance of the remaining 8 pixels by a proportionate amount. As a means of correcting for the nonlinearity of gray scales on the monitor and differences due to brightness bleeding across pixels, the luminance increases and summed decreases were not equal. When a homogeneous screen with each of the three luminance values used was measured, the background luminance was 7.26 fL (footlambert), the brightest luminance was 22.5 fL (value used for the central pixel), and the dimmest luminance was 4.22 fL (value used for the surrounding pixels). The hierarchical stimuli created from CB dots were constructed by placing the dots in a 5 × 4 matrix the size of one dark local letter. Luminance was measured for one of the CB small letters in isolation on the screen to determine the values just reported. The median luminance of one letter was 7.16 fL, very near the background luminance. The dark patterns appeared as dark gray on this background.

CB letters were placed in the 5 × 4 matrix used for the dark stimuli to form the global letter. In this way, the dark and CB patterns were created from the repetition of local letters to form a global letter. A Fourier analysis demonstrated that frequencies below three cycles per degree were all but eliminated in CB stimuli.[6] Testing was performed in a darkened room, and luminance levels were calculated under the same conditions.

Procedure. The display apparatus was the same as before. As in Experiment 2, all patterns were centrally presented. Dark stimuli and CB stimuli were presented on alternate trials. Participants were instructed to ignore the difference in dark and CB patterns and to indicate which target letter was present on each trial. Thus, the task was the same as in Experiments 1 and 2.

Because target and response finger were confounded in the previous experiments, 8 participants responded by pressing one of two keys to make their responses, and 8 responded by vocalizing the target letter. Voice onset time and manual reaction time were both measured to the nearest millisecond. This manipulation produced no differences in level repetition effects, and the data were pooled (see Table 4).[7]

Unlike in Experiments 1 and 2, there were three blocks of trials that varied in the probability that a target would occur at the global or local level. In the baseline or "neutral" block, global and local targets occurred equally often, as in Experiments 1 and 2. In one block, dark global targets occurred on 75% of the trials and dark local targets on 25% (.75g block). In another block, dark local

targets occurred on 75% and dark global targets on 25% (.25g block). CB patterns alternated with dark patterns in all cases. Global or local targets occurred 50% of the time for CB patterns in all blocks (.50g blocks). Only the probability schedule of dark patterns was varied because the question was whether or not participants could prepare for a global or local target (low vs. high spatial frequencies) on an upcoming trial after responding to a pattern with only higher frequencies. Because participants were forced to use higher frequencies to discriminate CB targets, the question was whether or not response times to dark global targets would be facilitated when global targets were more probable. Half of the participants were tested in the order .75g, .50g, and .25g, and half were tested in the opposite order of .25g, .50g, and .75g. All participants were fully informed about the probability schedule before each block of trials.

Results

The first critical analysis in Experiment 3 concerned the effect of CB patterns on response time to subsequent dark patterns. The dark patterns were exactly like those used in the first two experiments.

Mean reaction times were calculated, for each participant and each cell of the design, for the dark patterns (probes) as a function of the target level in the preceding CB stimulus (primes; see Footnote 7). Cells included letter repetition (same letter vs. different letter), target level in dark patterns (global vs. local), and target level in preceding CB patterns (same level vs. different level).

Neutral condition (.50g): Effects of CB prime on dark probes. The major question was whether or not the level-specific priming found in Experiments 1 and 2 for dark patterns would be eliminated by a preceding CB pattern prime. As a means of addressing this question, the data from the .50g block were analyzed first because this was the same probability schedule as used in Experiments 1 and 2, and it provided the most direct test of the question (see Table 5).

As shown in the upper portion of Figure 7, there were no effects of level repetition. If anything, the effects were reversed in one case. Reaction times were longer for global targets preceded by global targets than for global targets preceded by local targets (although this effect was not significant). The main effect for probe level, $F(1, 15) = 5.26$, $p < .05$, $MSE = 9,125$, reflected a 39-ms overall

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[6] I thank Robert Fendrich for his guidance in constructing the stimuli and for performing the Fourier analysis.

[7] Analyses showed that response mode produced response times that were 171 ms longer for vocal than for manual responses, $F(1, 14) = 28.63$, $p < .001$, $MSE = 4,934$, but this difference did not interact with level-specific repetition effects (see Table 4). Analysis of vocal and manual responses separately showed that response times were 52 ms faster for different letters than for same letters, $F(1, 7) = 9.71$, $p < .02$, $MSE = 4,377$. Letter repetition effects were 17 ms in the same direction for manual responses but did not reach significance. In neither case did letter repetition interact with level repetition, and there was no main effect of level repetition. The data from the participants using one mode and those using the other mode were pooled for the analysis presented in the text.

Table 4

Experiment 3: Mean Reaction Times (in Milliseconds) for Global and Local Dark Targets Preceded by Contrast-Balanced Targets for Participants Using a Manual Response and for Participants Using a Verbal Response

Expectancy (G–L probability)	Manual response				Verbal response			
	(g)G	(l)G	(l)L	(g)L	(g)G	(l)G	(l)L	(g)L
50g (50–50)	468	456	433	424	607	643	584	561
25g (25–75)	451	507	430	416	736	733	595	594
75g (75–25)	444	471	417	439	590	593	630	609
M	454	478	426	426	644	656	603	588

Note. The overall variance was more than twice as large for voice as for manual responses (*SEs* = 13.4 and 5.13, respectively). Yet, in neither case was there evidence for level-specific priming. g = global target on $N - 1$; l = local target on $N - 1$; G = global target on N; L = local target on N.

advantage for local targets (nearly the same as the 41-ms local advantage observed at the 1-s ITI in Experiment 2).

Response times for same letters were 35 ms slower than response times for different letters, $F(1, 15) = 9.84, p < .01, MSE = 3,838$, replicating the letter repetition effects shown in the previous experiments. Most important, there were no significant level repetition effects or interactions between level repetition and target letter repetition. CB patterns did not produce level-specific priming for a subsequent dark target. As shown in the upper part of Table 5, level-specific repetition effects were absent. It is important to note that although level repetition effects disappeared, letter repetition effects remained. The distinction between level repetition and letter repetition was again supported.

Neutral condition (.50g): Effects of dark primes on CB probes. The same analysis was performed for CB probes preceded by dark primes (lower portion of Table 5). Again,

Table 5

Experiment 3: Analysis of Variance Results, Neutral Probability

Source	MSE	F(1, 15)	p
Dark targets preceded by CB primes			
PriL (same–different)	7,006	0.14	.715
ProL (global–local)	9,125	5.26	.035*
PriL × ProL	7,960	1.05	.323
TLet (same–different)	3,838	9.84	.007*
PriL × TLet	8,358	2.79	.112
ProL × TLet	7,636	0.29	.602
PriL × ProL × TLet	4,145	1.24	.284
CB targets preceded by dark primes			
PriL (same–different)	7,887	0.56	.530
ProL (global–local)	8,443	0.69	.577
PriL × ProL	5,427	0.04	.842
TLet (same–different)	10,113	22.62	.001*
PriL × TLet	4,838	8.56	.010*
ProL × TLet	3,276	1.98	.177
PriL × ProL × TLet	4,989	1.57	.227

Note. CB = contrast balanced; PriL = prime level; ProL = probe level; TLet = target letter.
*p < .05.

there was no level repetition main effect, but there was a significant letter repetition effect, $F(1, 15) = 22.62, p < .001, MSE = 10,113$. As before, response times for same letters were 55 ms slower than those for different letters. However, unlike the analysis of CB primes on dark probes, there was a significant interaction between level repetition and letter repetition, $F(1, 15) = 8.56, p < .01, MSE = 4,838$. Same letters produced a level repetition effect of dark targets on CB targets, with response times being 47 ms shorter for same-level than for different-level conditions. (The magnitude of the level priming effect for the same-level condition was similar to that of previous studies in which priming occurred for both same-letter and different-letter conditions.) The simple comparison revealed only a trend in this direction as a result of increased variability, $F(1, 15) = 3.68, p < .08, MSE = 4,976$. Conversely, different letters produced no hint of a level repetition effect, and, if anything, response times were in the opposite direction. Different-level response times were 24 ms faster than same-level response times, although this difference did not reach significance.

These findings are consistent with a letter matching process that is better if the level remains the same than if it changes. A small-sized local target in a dark stimulus facilitated response only when the same target appeared in the CB stimulus at the local level (615 ms for same level vs. 651 ms for different level). A large-sized global target in a dark stimulus facilitated response only when the same target appeared in the CB stimulus at the global level (602 ms for same level vs. 662 ms for different level). When the target letter changed, local responses were similar for the same-level (538 ms) and different level (530 ms) conditions, and global responses were, if anything, reversed (582 ms for same level and 541 ms for different level).

As reported by others (Hughes et al., 1990; Lamb & Yund, 1993), CB patterns produced no significant difference between overall global and local response times (597 ms vs. 583 ms). CB stimuli eliminated baseline differences in reaction time between global and local identification.

Effect of probability manipulations. The probability of the dark stimulus was varied between blocks of trials to determine whether expectation of a global or local target
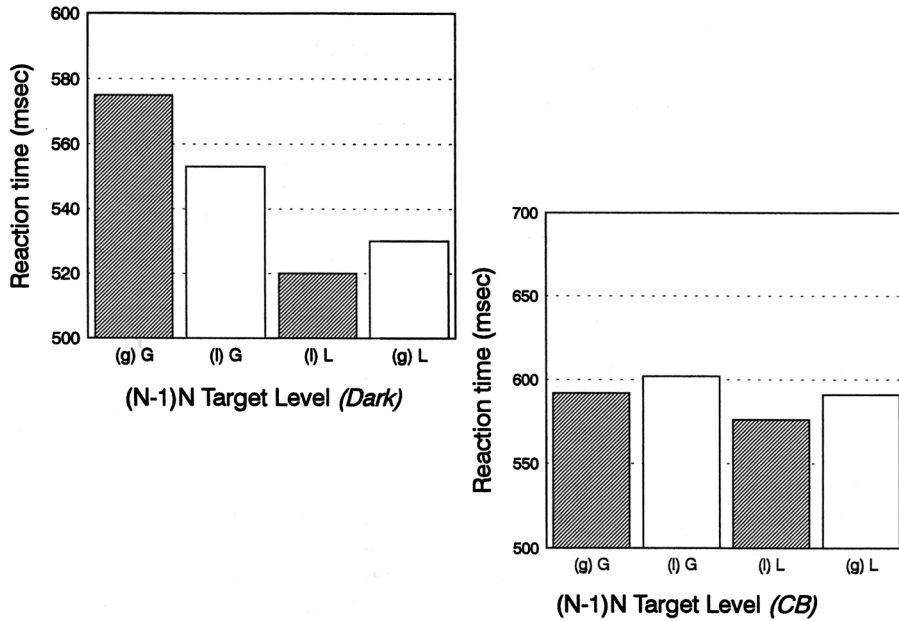
Figure 7. Mean reaction time for dark global and local targets as a function of the target level in the preceding contrast-balanced (CB) stimulus (on left) and for CB global and local targets as a function of the target level in the preceding dark stimulus (on right). The lowercase letters (g and l) refer to the global or local target level on the previous trial, and the uppercase letters (G and L) refer to the global or local target level for the response times shown.

with both lower and higher frequencies could override the lack of lower frequency information in a CB prime. Response times for dark probes were analyzed as a function of the CB prime target level for the globally likely (.75g) and locally likely (.25g) probability schedules. The results are presented in Table 6. As in the neutral conditions, local response times were, overall, faster than global response

Table 6
Experiment 3: Analysis of Variance Results for Probability Schedules .75g (Global Targets More Likely) and .25g (Local Targets More Likely)

Source	MSE	F(1, 15)	p
PG (.75g–.25g)	48,859	0.78	.605
PriL (same–different)	5,985	2.55	.128
PG × PriL	6,917	0.59	.540
ProL (global–local)	8,108	16.13	.001*
PG × ProL	12,251	7.95	.012*
PriL × ProL	4,516	0.31	.590
PG × PriL × ProL	5,909	3.76	.069
TLet (same–different)	7,526	7.15	.017*
PG × TLet	6,281	2.32	.146
PriL × TLet	3,252	10.42	.006*
PG × PriL × TLet	6,396	0.94	.652
ProL × TLet	3,510	0.53	.515
PG × ProL × TLet	4,774	1.44	.247
PriL × ProL × TLet	2,728	3.25	.088
PG × PriL × ProL × TLet	3,471	1.65	.217

Note. PG = probability of global; PriL = prime level; ProL = probe level; TLet = target letter.
* p < .05.

times, $F(1, 15) = 16.13, p < .001, MSE = 8,108$. Also, probability manipulations did affect overall response time, as revealed in a significant interaction between probability schedule and probe level, $F(1, 15) = 7.95, p < .02, MSE = 12,251$. Reaction times for the various probability schedules are shown in Table 7. There was a 39-ms local advantage in the .50g condition that increased to an 84-ms local advantage in the .25g condition and decreased to a 6-ms local advantage in the .75g condition. The local advantage increased by 45 ms when local targets were more probable and decreased by 33 ms when global targets were more probable.

Although level advantage changed over probability schedules, level-specific priming effects were unaffected by probability schedules. The Prime Level × Probe Level interaction did not reach significance (see Table 6 and Figure 8). Expectancy did influence overall reaction time for the expected target level, but this did not affect level-specific priming effects.

Level-specific priming from trial N − 2. One question that arose was whether or not there was level-specific priming from the most recent dark stimulus (i.e., from trial $N − 2$). Did the insertion of a CB trial between two dark trials eliminate level repetition effects, or were these effects still present but camouflaged in the data analysis as a result of the design? This question was addressed by examining reaction time differences on trial N when that trial was dark as a function of the level of the target on trial $N − 2$, which was also dark. There was no evidence of a level priming effect from $N − 2$, $F < 1$. Any priming effect left over from

Table 7

Experiment 3: Mean Reaction Times (in Milliseconds) for Dark Patterns for Probability Schedules .75g (Global Targets More Likely [G]) and .25g (Local Targets More Likely [L])

Probability schedule (G–L probability)	Global target	Local target
0.25g (25–75)	621	537
0.75g (75–25)	558	552

trial $N - 2$ was completely eliminated by the introduction of a CB stimulus.

This brings to bear the question of whether or not $N - 2$ influences the response on N even when a CB stimulus does not occur between two dark stimuli. I addressed this question by going back to the data in Experiment 2. When target letter and ITI were collapsed, there were sufficient numbers of triads to address this question. The triads were coded with the number 2 after the signifier for the target level on trial
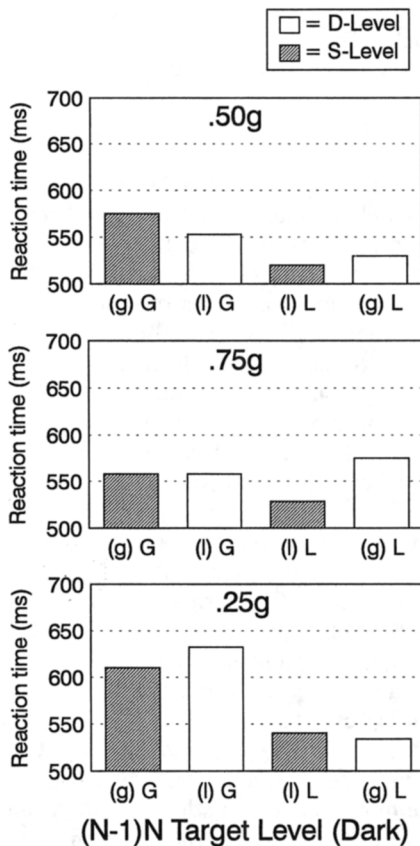

Figure 8. Mean reaction time for global and local targets on trial N as a function of the target level on the previous trial $N - 1$ for probability schedules of dark patterns. The lowercase letters (g and l) refer to the global or local target level on the previous trial, and the uppercase letters (G and L) refer to the global or local target level for the response times shown. D-Level = different level; S-Level = same level.

$N - 2$, a 1 after the signifier for the target level on trial $N - 1$, and a 0 after the signifier for the target level on trial N. For instance, L2-L1-L0 (L = local, G = global) refers to three local targets in a row. G2-L1-G0 refers to a global target followed by a local target and then a global target.

A three-variable ANOVA was performed with the target level on trial N (global vs. local) as one variable, the target level (global vs. local) on trial $N - 1$ as a second variable, and the target level (global vs. local) on trial $N - 2$ as a third variable. This analysis revealed that level repetition effects were influenced by the target level on $N - 2$ and were cumulative. There was a three-way target-level interaction among $N - 2$, $N - 1$, and N, $F(1, 11) = 6.98$, $p < .03$, $MSE = 1,103$, and both of the two level interactions, between $N - 2$ and N and between $N - 1$ and N, were significant, $F(1, 11) = 23.50$, $p < .001$, $MSE = 1,921$, and $F(1, 11) = 21.44$, $p < .001$, $MSE = 1,660$, respectively. Table 8 shows the mean response times for each sequence triad.

Simple comparisons revealed that L2-L1-L0 produced response times that were 34 ms faster than those produced by G2-L1-L0, $F(1, 11) = 8.90$, $p < .02$, $MSE = 822$. This difference increased to 98 ms between L2-L1-L0 and G2-G1-L0, $F(1, 11) = 29.21$, $p < .001$, $MSE = 1,997$. Global target sequences were affected in a similar manner. G2-G1-G0 produced response times that were 48 ms faster than those produced by L2-G1-G0, $F(1, 11) = 12.67$, $p < .01$, $MSE = 1,075$, and this difference increased to 65 ms between G2-G1-G0 and L2-L1-G0, $F(1, 11) = 24.81$, $p < .01$, $MSE = 1,720$.

Errors. The error rate for dark targets was 4.3%, and the error rate for CB targets was 7.3%. An analysis with same or different letter, same or different level, and probability schedule for dark targets revealed no significant main effects or interactions. The error rate for same level was 3.7%, and the rate for different level was 5.1%.

An analysis with global or local response times for CB targets also produced no significant differences. Errors were 7.4% for global targets and 7.1% for local targets.

Discussion

In Experiment 3, the role of spatial frequency in level-specific priming was evaluated directly. The data demonstrate that elimination of spatial frequency differences between global and local forms also eliminated level-specific priming effects. In other words, level priming was all but eliminated when parsing of global and local levels could not be performed on the basis of spatial frequency differences between the two levels on trial $N - 1$. This elimination was present even though a CB stimulus contained two levels of structure.

To my knowledge, there is no physiological evidence that cellular responses to different spatial frequency values persist in the visual system for up to 3 s after stimulus offset (the longest ITI used in Experiment 2). However, spatial frequency could appear as if it persisted if its value were coded in a representation of attentional weights. These weights could then direct attention to spatially filtered chan-

Table 8

Experiment 2: Mean Reaction Times for Same Level and Different Levels Over Three Sequence Trials for Global and Local Targets

Target	Reaction time (in ms)
Local	
L2-L1-L0	548
G2-L1-L0	582
L2-G1-L0	581
G2-G1-L0	646
Global	
G2-G1-G0	570
L2-G1-G0	618
G2-L1-G0	629
L2-L1-G0	635

Note. L2 = local target on trial $N - 2$; L1 = local target on trial $N - 1$; L0 = local target on trial N; G2 = global target on trial $N - 2$; G1 = global target on trial $N - 1$; G0 = global target on trial N.

nels on a subsequent trial. In the model shown in Figure 4, selectively attending to global or local targets is assumed to require initial parsing of global and local levels into different channels. Location differences would be of little benefit in parsing the shapes in these experiments because the global and local shapes inhabit the same coordinate spatial locations. However, parsing by spatial frequency should be easy and efficient.

This model proposes that attentional allocation (i.e., changing the weights) to spatially filtered streams of processing occurs relatively early. It further suggests that the weights are adjusted by an interactive loop between processing channels that result from parsing on the one hand and attentional weighting on the other. As the evidence for the presence of a target in one or the other processing stream grows, more attentional weight is given to that stream and less to the remaining stream. This is represented in Figure 4 as an increase in attentional weights over time. Level-specific repetition effects are attributed to a lasting trace of the attentional weights that were successful on a previous occasion on which the stimulus and task demands were similar. When a stimulus pair with a target at the same level appears on trial N and trial $N - 1$ (as in Figure 4, Trial 2), reaction time is facilitated. When the target level changes (as in Figure 4, Trial 3), the weights must then change accordingly. In this model, the spatial frequency values themselves need not persist over a 3-s ITI. The weights assigned to the processing streams created by spatial frequency filtering persist to produce the pattern of level-specific priming observed in the previous experiments. The weights form a type of attentional print that lasts over time. (Note that form processing and form identification are separated in the model, an independence that has received strong support from the study of patients with visual associative agnosia [see Farah, 1990]. These patients can perceive the form clearly [e.g., draw it correctly and match it to other forms], but they are not able to identify the form or describe its function.)

As this model predicted, the pattern of influence of CB targets on subsequent dark targets was different from the influence of dark targets on subsequent dark targets (Experiments 1 and 2). The level-specific priming effects observed in Experiments 1 and 2 were absent. A CB global or local target did not produce the typical slower reaction time for a subsequent target at the opposite level either when the target letter was the same or when it changed.

The findings of Experiment 3 demonstrated that level-specific priming effects could be eliminated by eliminating the ability to parse by spatial frequencies in the prime. In a replication and extension of the present work, Kim (1994) replicated these effects. Also, Lamb and Yund (1993) found a reduction of global advantage in a block of only CB stimuli, but they did not evaluate priming effects, and Shulman and Wilson (1987) found that directing attention to the global or local level affected detection of a high-frequency or low-frequency sine wave grating in a direction consistent with the present findings.

These results, in combination, are consistent with the hypothesis that there exists an attentional print that records cumulative weight assignments to processing streams created by parsing on spatial frequency content. When the target appeared at the same level on trial $N - 1$ and $N - 2$ in dark stimuli (Experiment 2), level-specific priming was evident for both $N - 1$ and $N - 2$, with level priming effects increasing over trials. However, when a CB pattern was presented on trial $N - 1$ and a dark pattern on trial $N - 2$ (Experiment 3), the target level on $N - 2$ had no effect on trial N. When spatial frequency could not be used to parse the two levels (i.e., in CB patterns), level-specific priming was eliminated even from the most recent dark pattern ($N - 2$). When spatial frequency parsing fails, other strategies must be used to perform the task, and the information in the attentional print is lost or replaced. These effects are represented in the model shown in Figure 9. Trial 4 represents the continuation of the sequence of trials represented in Figure 4. On Trial 4, a CB stimulus appears, and the parsing fails. On Trial 5, the system acts as it did on Trial 1 before an attentional print had been created. This type of model could also be applied to the shape-independent priming reported by Maljkovic and Nakayama (1994) for color and location in visual search displays that produce pop out. The difference would be that the dimensions used for parsing would be those that segregate the unique features from the distractor features (in their case, location or color).

Experiment 4

Experiment 3 demonstrated that removing spatial frequency differences between global and local forms changed level-specific priming effects. However, there were more differences between the dark and CB patterns than simply spatial frequency. By design, the patterns were different in contrast and thus different in perceived brightness. They were also different in perceived color (black vs. white). In Experiments 1 and 2, in which level-specific priming was robust, the patterns never varied in visual attributes from

Trial 4 - Contrast Balanced Pattern (High Frequency Only)
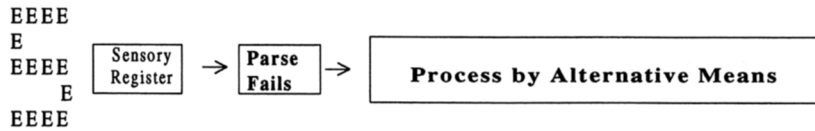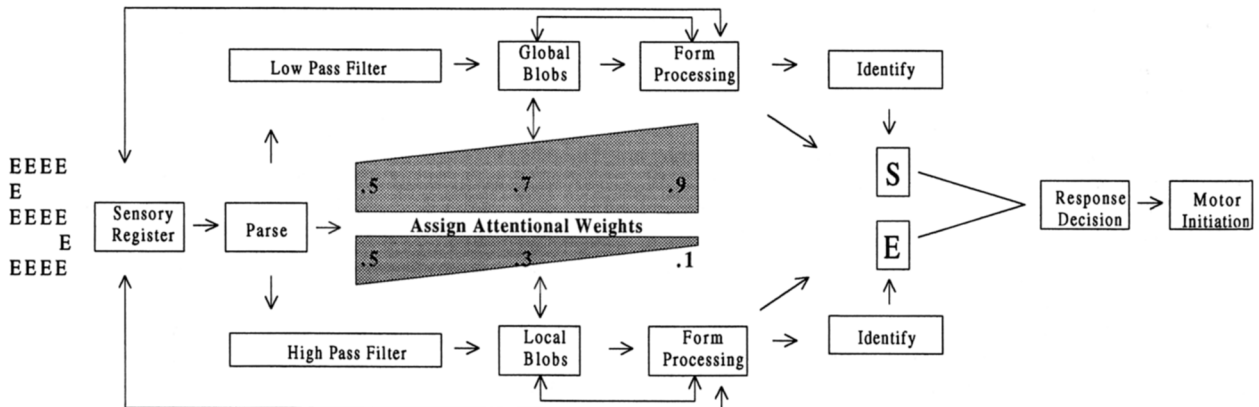

Trial 5 - Regular Grey

Figure 9. Continuation of example of model in given trial sequences (refer to Figure 4 for Trials 1–3). Trial 4 represents the presentation of a contrast-balanced pattern in which lower spatial frequencies were removed (as shown in Figure 6). Trial 5 represents the presentation of a dark pattern as in Trials 1, 2, and 3 in Figure 4 (see text for full discussion).

one trial to the next. It is possible that differences in these attributes between a stimulus on one trial and the next contributed to the absence of level-specific priming in Experiment 3. It is also possible that any mismatch between the features of a target on one trial and those on a subsequent trial would change level-specific priming. Experiment 4 was designed to test these possibilities.

The same procedures used in Experiment 2 were used in Experiment 4, except that polarity, contrast, or color was also manipulated. In one condition, the hierarchical patterns were of either the same polarity or a different polarity across trials. In another condition, they were either the same or a different color. In a third condition, they were of either the same or a different contrast. In all cases, spatial frequency differences between global and local patterns were present and could be used to parse the stimulus.

A second purpose for examining the effects of these attributes was to test the attentional print hypothesis. The term *attentional print* refers to a lasting trace of the attentional weights assigned after early parsing operations. When spatial frequency differences between global and local levels were present, level-specific priming resulted (Experiments 1 and 2). Because the hierarchical stimuli were the same color on any given trial, color could not be used to parse global from local forms. A global form was created from local forms, so objects at both levels had to contain the same color even though they could vary in spatial frequency. Under these conditions, color should not be part of

the attentional print because it would not be useful for spatial parsing. It would be response irrelevant. Unlike in Maljkovic and Nakayama's (1994) studies, color would not be useful in parsing and, therefore, should not produce priming effects. The same logic holds for contrast and polarity.

The first question addressed in the present experiment was whether or not repeating a stimulus with the same color, polarity, or contrast produces level priming effects. For example, if color changed from one trial to the next, there obviously would be a mismatch between the features of the target on the previous trial and the features of the target on the present trial. The question was whether or not this mismatch would slow response time. The attentional print hypothesis predicts that it would not, because color differences could not aid in selection on the previous trial.

The second question was whether or not there would be an interaction between level repetition effects and color, polarity, or contrast repetitions. These factors differentially affect visual input but would not be useful in parsing the stimulus into streams for attentional selection. However, spatial frequency information would still be available to differentiate global from local target levels. If it is the use of spatial frequency information that produces level-specific priming effects in hierarchically structured forms, then color, contrast, or polarity should not produce priming; only level should produce priming.

Method

Participants. Thirty-six new participants were recruited to take part in Experiment 4. They were separated into three groups. The same criteria were used as in the previous studies. All participants were tested at the Veterans Administration facilities in Martinez and were recruited from local college communities. All gave informed consent before the experimental session began.

Stimuli. The stimuli and apparatus were the same as described in Experiment 1, except that three sets of hierarchical patterns were constructed. One set was colored either red or green. The second set was either dark gray or white on a light gray background. Contrast was equated. The background luminance was 7.24 fL. The dark stimulus was 6.45 fL, and the white stimulus was 8.35 fL. Values were corrected for pixel bleed by equating luminance measures for the middle local letter in each type of stimulus. The third set of stimuli varied in luminance. The background luminance was the same, but two values of dark and two values of white were used.

Procedure. The procedure was the same as before. Participants were told to indicate whether an H or S appeared on each trial by pressing a key as fast as possible. The H or S could be local or global but never both. Polarity, contrast, and color were between-groups variables. Each participant saw stimuli that could appear in one of two polarities, two contrasts, or two colors. Because the contrast condition had both white and dark versions, 6 participants in this group responded to white stimuli and 6 to dark stimuli.

Experimental trials were arranged to form all possible combinations of trial pairs. In each condition, same or different levels and same or different target letters were orthogonally combined with same or different color, polarity, or contrast. As a result of experimenter error, the number of trials for one attribute was different from that for the other two. Participants in the polarity condition experienced 256 trials. Participants in the color and contrast conditions experienced 512 trials each in two blocks of 256. In all other respects, the procedure was the same as that in Experiment 2.

Results

The data were analyzed in a mixed-design ANOVA with attribute (polarity vs. contrast vs. color) as a between-groups variable and level repetition (same level vs. different level), letter repetition (same letter vs. different letter), and attribute value repetition (same vs. different; collapsed over polarity, contrast, and color) as within-subject variables. The overall analysis resulted in a main effect of level repetition. Response times were 41 ms faster in the same-level condition than in the different-level condition, $F(1, 33)$ = 26.99, $p < .001$, MSE = 4,456. As can be seen in Table 9, this effect did not interact with attribute.

Level repetition did interact with letter repetition, $F(1, 33)$ = 15.55, $p < .001$, MSE = 1,223. Larger level repetition effects occurred for same letters than for different letters, similar to some of the effects reported in the previous experiments. However, level effects did not disappear. Simple comparisons demonstrated that whether or not the target letter changed between trials, level repetition was evident. The same letter on successive trials produced a 58 ms faster response time in the same-level condition than in the different-level condition, $F(1, 35)$ = 34.71, $p < .001$, MSE =

Table 9

Experiment 4: Analysis of Variance Results

Source	df	MSE	F	p
ProA (color, polarity, contrast)	2, 33	91,103	0.49	.625
PriV (same–different)	1, 33	617	0.15	.704
ProA × PriV	2, 33	617	1.32	.280
ProL (same–different)	1, 33	4,456	27.00	.001*
ProA × ProL	2, 33	4,456	0.56	.583
PriV × ProL	1, 33	424	3.52	.066
ProA × PriV × ProL	2, 33	424	2.94	.065
TLet (same–different)	1, 33	1,599	5.42	.025*
ProA × TLet	2, 33	1,599	0.98	.614
PriV × TLet	1, 33	429	0.01	.936
ProA × PriV × TLet	2, 33	429	5.41	.009*
ProL × TLet	1, 33	1,223	15.55	.000*
ProA × ProL × TLet	2, 33	1,223	0.94	.597
PriV × ProL × TLet	1, 33	342	1.14	.149
ProA × PriV × ProL × TLet	2, 33	342	1.88	.167

Note. ProA = probe attribute; PriV = prime value; ProL = probe level; TLet = target letter.
*$p < .05$.

1,692, whereas different letters produced a 24 ms faster response time in the same-level condition than in the different-level condition, $F(1, 35)$ = 10.02, $p < .01$, MSE = 1,088. Again, this effect did not interact with attribute. Level Repetition × Letter Repetition effects did not vary significantly across polarity, color, and contrast, as shown by the lack of an Attribute × Probe Level × Target Letter interaction in Table 9.

As in the previous experiments with a 1-s ITI (see Table 3), same letters produced slower response times than different letters, as reflected in a main effect of letter repetition, $F(1, 33)$ = 5.42, $p < .03$, MSE = 1,599.

The only other significant effect in the overall analysis was a three-way interaction among attribute, letter repetition, and attribute value repetition, $F(2, 33)$ = 5.41, $p < .01$, MSE = 429 (see Table 10). More important, this effect did not interact with level repetition, nor did level repetition interact with attribute repetition, both $Fs < 1$.

Global–local priming effects. As a means of determining whether the level-specific priming effects in the previous studies were replicated in Experiment 4 when color, polarity, or contrast was the same, the data were first ex-

Table 10

Experiment 4: Mean Reaction Time (in Milliseconds) for Same Letter and Different Letters When the Value of the Attribute Was the Same and When It Was Different on Trial N − 1 and Trial N

	Same		Different	
Attribute	Same letter	Different letter	Same letter	Different letter
Polarity	507	494	492	501
Contrast	519	505	524	501
Color	469	464	483	464

amined in a planned analysis limited to the case in which successive trials contained the same attribute value (same polarity, same color, and same contrast). Response times were analyzed for each probe level on trial N (global or local) for each prime level on trial $N - 1$ (global, local) for each attribute (polarity, contrast, color).

As shown in Figure 10 (left side of each graph), the pattern of results was similar for polarity, contrast, and color. Attribute produced no significant main effect or interactions, all $ps > .25$.

Response times favored local targets overall, $F(1, 33) = 23.90$, $p < .001$, $MSE = 1,405$. Consistent with previous results, there was a Prime Level × Probe Level interaction indicating level-specific repetition effects, $F(1, 33) = 31.58$, $p < .001$, $MSE = 2,232$. Simple comparisons showed that local response times were 43 ms faster when

preceded by a local target than when preceded by a global target, $F(1, 35) = 29.79$, $p < .001$, $MSE = 1,111$, and global response times were 46 ms faster when preceded by a global target than when preceded by a local target, $F(1, 35) = 22.36$, $p < .001$, $MSE = 1,674$. No other significant effects were present.

A second analysis was performed for conditions in which the attribute changed on successive trials, as it did in Experiment 3. This analysis was also a planned test to determine whether a change in visual features across trials would eliminate level-specific priming effects, as it did in Experiment 3.

Local targets were responded to more rapidly than global targets, $F(1, 22) = 6.91$, $p < .02$, $MSE = 2,015$. There was also a Prime Level × Probe Level interaction, $F(1, 33) = 17.05$, $p < .001$, $MSE = 2,725$. Simple comparisons showed that response times for global targets preceded by global targets were 23 ms faster than response times for global targets preceded by local targets, $F(1, 35) = 13.92$, $p < .001$, $MSE = 635$. Response times for local targets preceded by local targets were 50 ms faster than response times for local targets preceded by global targets, $F(1, 35) = 14.36$, $p < .001$, $MSE = 3,093$. These effects did not differ across attributes. There was no main effect or interaction for attribute, all $Fs < 1$.

Simple planned comparisons for attribute repetition across same and different trials showed that level-specific priming effects were not significantly different for local targets, $F < 1$, but were different for global targets, $F(1, 33) = 11.07$, $p < .01$, $MSE = 446$. Global repetition effects were reduced, although still present, when the attribute changed, whereas local repetition effects were not affected by these changes. Again, these effects did not differ across the three attributes, $F < 1$.

Stimulus-specific effects. Finally, level priming effects were evaluated for exact repetitions when both global and local letters were the same, when a letter at one level changed, and when both letters changed. The means are presented in Table 11. Level priming was found across all types of prime–probe relationships. The same target and distractor produced a 69-ms level repetition effect, $F(1, 35) = 44.41$, $p < .001$, $MSE = 1,915$. The same target with a different distractor produced a 46-ms level repetition effect, $F(1, 35) = 18.13$, $p < .001$, $MSE = 2,057$. A different target with the same distractor produced a 22-ms level repetition effect, $F(1, 35) = 5.50$, $p < .03$, $MSE = 1,642$, and a different target with a different distractor produced a 27-ms level repetition effect, $F(1, 35) = 14.18$, $p < .001$, $MSE = 915$. Whether or not the same stimulus with the same target and distractor was presented, level-specific priming occurred.

Errors. The overall mean error rate was 4.3%. Errors were analyzed with attribute as a between-groups variable and level repetition, letter repetition, and attribute repetition as within-group variables.

Error rates did not differ across attributes, $F < 1$. The only significant effects were a main effect of level repetition, $F(1, 33) = 31.49$, $p < .001$, $MSE = .001$, and a main effect of letter repetition, $F(1, 33) = 6.93$, $p < .02$, $MSE =$
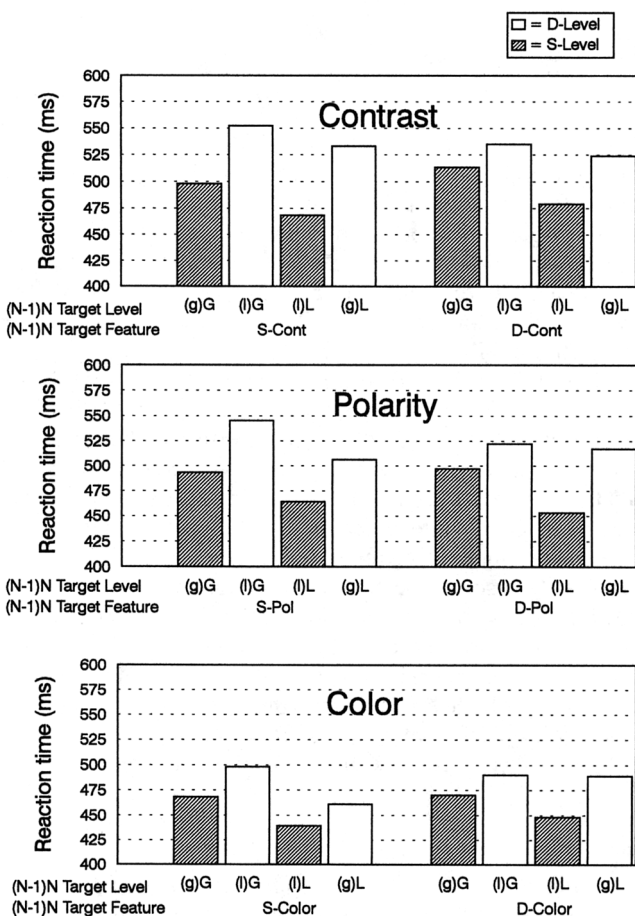

Figure 10. Mean reaction time for global and local targets on trial N as a function of the target level and attribute value on the previous trial $N - 1$ when contrast (S-Cont = same contrast, D-Cont = different contrast), Polarity (S-Pol = same polarity, D-Pol = different polarity), or Color (S = same, D = different) varied. The lowercase letters (g and l) refer to the global or local target level on the previous trial, and the uppercase letters (G and L) refer to the global or local target level for the response times shown. D-Level = different level; S-Level = same level.

Table 11

Experiments 1, 2, and 4: Mean Reaction Times and Level-Specific Priming (in Milliseconds) for Same Level and Different Level, Same Versus Different Letter, and Same Versus Different Distractor

| | Same-letter target | | Different-letter target | |
Level	Same-letter distractor	Different-letter distractor	Same-letter distractor	Different-letter distractor
		Experiment 1		
Same	576	568	588	575
Different	607	612	594	603
Priming	31*	44*	6	28*
		Experiment 2		
Same	573	594	564	582
Different	653	658	605	590
Priming	80*	64*	41*	8
		Experiment 4		
Same	458	483	480	471
Different	527	529	502	498
Priming	69*	46*	22*	27*

$* p < .05$ (simple comparison).

.002. The error rate for the same-level condition was 3.2%, and the rate for the different-level condition was 5.5%. The error rates for the same-letter and different-letter conditions were 5.0% and 3.7%, respectively. The pattern of errors was similar to the pattern of reaction time.

Discussion

In Experiment 4, the effects of changing color, polarity, or contrast on level-specific priming were evaluated. Significant level-specific priming was found for all three attributes for both global and local targets. These effects were present whether or not the attribute value changed on successive trials. Level-specific priming was not eliminated as it was in Experiment 3 in which lower frequencies of the prime stimulus were removed through contrast balancing procedures. In Experiment 4, higher and lower frequencies were present in all stimuli and could be used in selecting a potential target level.

There were some effects of changing attribute values between trials, but they could not account for the pattern of results in Experiment 3. Local targets preceded by local targets produced faster response times than local targets preceded by global targets. These differences were the same for color, polarity, and contrast whether the attribute value of the pattern changed or not. Although changes in attribute value on successive trials did affect the magnitude of level-specific priming for global targets, they did not eliminate them. There was a reduction in level priming when the attribute value changed across trials, but only for global targets. This reduction did not differ across color, polarity, and contrast. None of these attributes affected response times in the same manner as elimination of lower frequencies did in Experiment 3. All attributes produced significant and nearly identical level priming effects.

It is important to note that when a change in attribute

value affected level repetition effects (global targets), it was to reduce the repetition effects. This finding means that a simple mismatch between one stimulus and the next cannot account for the results. Mismatches between one pattern and the next should increase differences when the attribute value on two successive patterns changes; in this case, however, they decreased them.

The data from Experiment 4 demonstrated that the elimination of both global and local level priming effects in Experiment 3 could not be attributed to perceived brightness, contrast, or color changes between dark and CB patterns. When global–local patterns contained relatively high and low spatial frequencies, a target at the same level on successive trials produced faster responses than when target levels differed. This pattern of performance occurred whether or not the stimuli on successive trials differed in contrast, color, or polarity.

General Discussion

The results of the present set of studies support my argument that attentional weights that are assigned to dimensional values during selection influence performance over time. Level-specific priming occurred whether or not the object, shape, or location changed between one trial and the next. The type of priming reported here could not be attributed to mismatch across successive trials. Changes in color, polarity, or contrast did not eliminate the level priming effects. Only changes in spatial frequency across trials eliminated these effects.

The results have implications for several issues within psychology. They speak to the question of what spatial features can affect pattern reperceiving or reattending across time (Kahneman, Treisman, & Gibbs, 1992). They have implications for theories of global precedence (Navon, 1977), and they are relevant for neuropsychological theories

of global–local processing and the role of parietal function in attending to spatial features (Robertson & Lamb, 1991).

Attentional Prints and Perceptual Priming

Priming refers to the phenomenon that stimuli presented at one point in time have an effect on performance at another point in time. Perceptual priming has been found with a wide range of temporal lags (see Cooper, Schacter, Ballesteros, & Moore, 1992; Kersteen-Tucker, 1991; Musen & Treisman, 1990). The concept is very general, and the purpose of investigations of priming is little different from that of traditional investigations of learning and memory; there is one important distinction, however. Explanations of priming effects focus on what cognitive processes occurred during initial presentation of a stimulus that affected subsequent performance rather than focusing on forgetting and interference that occur between presentation and test. The question concerns how the stimulus was initially processed so as to influence performance at a subsequent time.

The present results have obvious implications for short-term (and maybe even long-term) repetition priming of visual objects. Unlike so many of the perceptual priming effects reported in the literature (see Tulving & Schacter, 1990), priming based on spatial frequency or global–local selection was not limited to the repetition of the same stimulus in its entirety. Level-specific priming occurred whether or not there was repetition of the object itself (repetition of the same global letter with the same local letter) and whether or not there was repetition of the semantic information of the form (i.e., repetition of the same letter independent of target level). Current theories of perceptual priming are not adequate to account for these effects.

It might be argued that spatial frequencies are part of the structural description of an object and are thus consistent with priming effects found for possible but not impossible figures (Schacter, Cooper, Delaney, Peterson, & Tharan, 1991). However, this explanation is not satisfactory either. All of the stimuli in the present experiments were possible (although perhaps not usual) and equally so whether they contained a large range of spatial frequencies or not. Yet the absence of spatial frequency differences that could be used to parse the global and local levels eliminated level priming (Experiment 3). This was the case even though the hierarchical organization of the stimulus was maintained by constructing the stimuli with CB dots.

The model represented in the examples in Figures 4 and 9, and discussed as the data were reported, can account for all of the level priming effects reported here. During selection, certain computational processes based on spatial frequency information were used to segregate global from local forms and then to search the resulting processing streams for a target. Other features that were not useful for parsing and selection did not alter level-specific priming. When color, polarity, or contrast changed between trials, level priming was still present. When spatial frequency content changed between trials, level priming was eliminated.

One could argue that these attributes simply do not prime and that these dimensions are just fundamentally different from spatial frequency in this regard. However, Maljkovic and Nakayama (1994) have shown that color changes on successive trials do affect sequential priming when color is useful in discriminating the target from a background of different-colored distractors. They used a pop out type of visual search display (see Treisman & Gelade, 1980) and found cumulative priming effects across trials for color, location, and spatial frequency. Although their methods and those used here were very different, their data were consistent with the arguments presented here in showing that the features of color and spatial frequency produced priming when useful for target segregation in a visual search display.

I have called the record created by the prime an attentional print because I am proposing the existence of a lasting representation of how spatial features activated during attentional selection were used in performance of the task on a previous occasion. The concept of an attentional print is conceptually quite different from generally accepted ideas of representation. The print contains a record of how selection occurred that probably exists in parallel with what was selected. It leaves a trace of where attention has been and how it got there, something like a set of footprints leaves a trace of where an animal has been and the path it took.

If the computations used to search the prime are reactivated to search the probe but do not readily result in detection of a target on trial N, feature weights must be changed. It is this change that produces a cost in response time. If parsing on the basis of spatial frequency information is disrupted, as it was in Experiment 3, attention cannot be allocated to two spatial streams because the two streams do not exist. Level priming then disappears.

The data are consistent with automatic reactivation of the print when similarly organized patterns with similar task requirements are encountered. Neither global nor local reaction time advantages affected the magnitude of level-specific priming (cf. Experiments 1 and 2).

Global Precedence Theory

The experiments were not designed to test issues of global precedence directly (Navon, 1977). However, the results do have implications for these issues. First, the relationship between spatial frequency analysis and attending to global and local targets has been strengthened. Shulman and Wilson (1987) demonstrated that attending to global targets increased detection of lower frequency sine wave gratings, whereas attending to local targets increased detection of high-frequency gratings. The effects lasted for less than half a second and decreased over time.

Shulman and Wilson's (1987) results demonstrated that attending to global or local levels of a pattern involves the use of the spatial frequency differences in such patterns. The present findings extend their results by showing that a record of that use is present at higher levels in the visual system for longer durations and can be reactivated up to 3 s after the response to the previous stimulus (Experiment 2).

Second, the present data have implications for interpreting differences in performance found when expectancy of a target at the global or local level is varied (Kinchla et al., 1983; Robertson et al., 1988). Global targets preceded by global targets are more likely when the probability of a global target is increased, and local targets preceded by local targets are more likely when the probability of local targets is increased. This fact must be taken into account when considering changes in response time advantage for global or local targets across studies in the literature. Trade-offs in performance resulting from probability manipulations or cuing can be due to controlled attentional processes as well as automatic reactivation of attentional selection processes.

Relevance for Neuropsychology of Part–Whole Processing

The present results have important implications for data from neuropsychological studies examining the role of attention in global and local deficits in patient populations. In a previous study, Robertson et al. (1988) examined attentional capabilities in brain-damaged groups by varying the probability that a target would occur at the global or local level between blocks of trials. For healthy control groups, overall response time was fastest for targets occurring at the more probable level and slowest for targets occurring at the less probable level. There were both costs and benefits relative to an equally probable condition.

Groups of patients with lesions centered in the temporal–parietal junction showed a hemispheric difference in the overall speed in identifying a global or local target, but they showed normal trade-offs in performance produced by probability manipulations. Conversely, patients with lesions located more dorsally and limited to the parietal lobe showed no abnormal hemispheric differences in global or local advantage as well as virtually no effect of probability manipulations. In the initial report, level-specific priming effects were not evaluated.

The data from Robertson et al. (1988) were reanalyzed for level-specific priming, and the results were discussed by Rafal and Robertson (1995). Patients with unilateral temporal–parietal lesions who showed hemispheric differences in baseline response times also showed normal level-specific priming effects. However, for the parietal group, level-specific priming was absent. The reduction of level priming by parietal lesions was replicated in a second study (see Rafal & Robertson, 1995).

Patients with parietal damage did very well at the task and were even somewhat faster than normals in their overall response, but they showed virtually no level-specific priming (neither costs nor benefits). These findings mean that patients with damage in this area were able to select the correct target and respond within a reasonable amount of time. Their perceptual abilities were intact, and they were able to selectively attend to the target at one level or the other at the time they were searching for the target. However, they did not show evidence of normal level-specific

priming. The participants in this group may not have been able to use the spatial frequency of the pattern in the selection process, a situation that would be similar to that of normals when responding to CB stimuli in Experiment 3. Alternatively, these patients may have formed an attentional print but lost it within the 1-s interval between trials. Finally, they may not have created a print of how spatial frequency was used on the previous trial, which is consistent with Goodale and Milner's (1992) argument that parietal lobe function is a matter not so much of where but of how.

The source of the abnormality in parietal patients has not yet been determined. However, the data are intriguing because they demonstrate that attentional processes associated with the parietal cortex are more general than guiding attention to spatial locations (Posner, Walker, Friedrich, & Rafal, 1984). They also appear critical in guiding attention to spatial resolution or spatial frequency.

Attentional Prints, Priming Effects, and Object Files

The idea of reattending or reperceiving is basic to the attentional print but also basic to other theories of perceptual priming. Kahneman et al. (1992) proposed a theory of reperception in which they introduced the concept of an object file. Object files refer to a collection of features in a display that are conjoined retrospectively across time and space so as to perceive a particular instance of an object. These object files produce object-specific priming with intervals between prime and probe of less than a second. In the experiments reported here, both same and different forms produced level priming across intervals of 1, 2, and 3 s that were present whether the object changed or not. These data are not consistent with an object file account.

Nevertheless, object files have similarities to attentional prints, and a discussion of the similarities and differences is in order. Object files refer to mechanisms that are responsible for the reactivation of features to create objects from previously viewed stimuli that are bound over space and time. Attentional prints also reactivate the use of features (in the present case, spatial frequency). However, in most other senses, object files and attentional prints are quite different. Object files describe features that are bound across time and space to form a particular object. Attentional prints need not be object specific. They are more like action files that bind a type of stimulus structure to a particular operation or internal act that guides efficient selection. In object files, the representation of object features is reactivated across time and space. In attentional prints, the representation of how features were used in a previous selection process is reactivated by the stimulus and task parameters.

An attentional print may precede or follow the formation of an object file and, like an object file, can appear as if features persist across time. Neither object files nor attentional prints propose direct feature persistence. In an object file, the trace of the previous stimulus is reactivated at the time of selection on trial N. An attentional print reactivates the weights assigned to candidate processing streams used during selection.

In theory, an attentional print will be formed only when attentional selection is necessary. In Experiment 4, the color, contrast, or polarity of a hierarchical pattern changed between trials, but on any one trial these features were the same value for global and local forms. Color, contrast, and polarity were useless in differentiating one potential target level from another. Consistently, a change in these features did not affect level priming on the next trial because the features were not useful in guiding attention to local or global spatial structure.

Summary

The data presented here demonstrate that short-term repetition effects of attended objects can be linked to the attended spatial structure of a target but need not be target specific. When repetition effects are tied to the target, an object file can account for the effects as well as an attentional print. When repetition effects are not tied to the specific target, some other mechanism such as an attentional print must be considered. The attentional print influences a subsequent selective process by its link to a historical event of selection with similar stimulus and task requirements. It is a model of how spatial features (and, most likely, nonspatial features) can be used to guide attentional selection and reselection.

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