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Sequential Priming in Hierarchically Organized Figures: Effects of Target Level and Target Resolution

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Three experiments are reported in which participants identified target letters that appeared at either the global or local level of hierarchically organized stimuli. It has been previously reported that response time is facilitated when targets on successive trials appear at the same level (L. M. Ward, 1982; L. C. Robertson, 1996). Experiments 1 and 2 showed that this sequential priming effect can be mediated by target-level information alone, independent of the resolution, or actual physical size, of targets. Target level and resolution were unconfounded by manipulating total stimulus size, such that global elements of the smaller stimuli subtended the same amount of visual angle as local elements of the larger stimuli. Experiment 3, however, showed that when level information is less useful than resolution in parsing targets from distractors, resolution does become critical in intertrial priming. These data are discussed as they relate to the role of attention in local vs. global (part vs. whole) processing.

The organization of visual information plays a critical role in perception. Emergent properties that are not inherent in the individual components of complex figures exert powerful effects on perceptual processing (see, e.g., Banks & Prinzmetal, 1976). Within a pattern, parts can be organized into larger, meaningful wholes that have visual properties in their own right. These emergent, holistic percepts may in turn affect the recognition of the pattern's constituent parts (e.g., Palmer, 1980; Pomerantz, Sager, & Stoever, 1977).

One example of part–whole interaction involves the processing of hierarchical letter stimuli. In these stimuli, a set of homogeneous letters can be used as local elements and are configured to form another letter, that is, the global shape. Participants are asked to identify a target letter that can appear at either the local or the global level (Navon, 1981, 1983). Navon (1977) argued that the global shape of such complex figures is generally identified prior to the component parts, that is, the local elements. His theory of global precedence proposes that perceptual processing proceeds from the analysis of the global form of a complex figure to its local details, either through sequential analysis or through faster or stronger activation of global over local information (e.g., Saarinen, 1994). Furthermore, there are indications that global processing not only enjoys temporal dominance but that it can actively interfere with local processing as well (e.g., Pomerantz, 1983). This phenomenon of "global interference" is largely unidirectional—local elements in a figure do not seem to exert the same inhibitory effects on global processing (e.g., Luna, Merino, & Marcos-Ruiz, 1990; see also Robertson, Lamb, & Zaidel, 1993). Since the initial demonstration of global precedence, a great number of studies have explored the sensory and attentional mechanisms that underlie responding to local and global aspects of patterns both in healthy and in neurologically impaired populations (Kinchla & Wolfe, 1979; Lamb & Robertson, 1990; Martin, 1979; Navon & Norman, 1983; Robertson & Delis, 1986; Robertson & Lamb, 1991; Robertson, Lamb, & Knight, 1988; Sergent, 1982).

The discussion of processing of hierarchical stimuli has thus far focused on level-mediated effects that occur during the course of a single trial. The question that we address in this article is whether the same mechanisms that affect responding to the local or global level within a given figure on one trial may also influence subsequent perception on the next. Ward (1982) was the first to demonstrate that reaction time (RT) to identify a particular component in hierarchical stimuli was affected by the target level (local or global) of the stimulus on the preceding trial. Independent of target identity, the speed of participants' responding was faster on trial $N + 1$ if a target appeared at the same level as the target on trial N. This effect has been referred to as *sequential priming*. More recently, Robertson, Egly, Lamb, and Kerth (1993) and Robertson (1996) replicated and further explored this level-specific sequential priming effect.

The latter study, in particular, examined the possibility

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that these sequential level effects are mediated by the spatial frequency content of the different levels and was based on previous data that linked spatial frequency and within-trial, level-mediated effects (Hughes, Fendrich, & Reuter-Lorenz, 1990; LaGasse, 1993; Shulman, Sullivan, Gish, & Sakoda, 1986; Shulman & Wilson, 1987). Specifically, Robertson (1996) found that level-repetition effects depended on spatial frequency differences between local and global components. When hierarchical stimuli were constructed from contrast-balanced dots—a manipulation that selectively removes low-frequency information but leaves high spatial frequencies and the global–local relationship intact—sequential priming disappeared. Robertson (1996) proposed that priming occurs because there is reactivation in similar spatial frequency regions across successive trials. In her model, this occurs because there is an "attentional print" that remains after the trial ends, which contains both the features that were used in the process of selection (e.g., spatial frequency) and how the values of these features were weighted. There are at least two stages in her model. The first is a parsing process that uses frequency spectra to separate the stimuli into levels of structure in which a potential target may appear. The second is an identification process that determines the target shape. It is the first stage that seems to produce level priming, and it is this stage that is thought to be based on the differences in spatial frequency between the two levels. For example, if information for global identification had been attended at *X* cycles/deg on trial *N*, then processing on trial $N + 1$ would be facilitated in the same frequency region independent of target identity. This mechanism would suggest that the sequential priming effects for hierarchically structured patterns would be a function of target spatial frequency. Support for this model was found by reducing low spatial frequencies through contrast balancing, a procedure that retained the two-leveled percept of the hierarchical patterns as well as their overall size. Eliminating the spatial frequency differences between global and local elements abolished the level-specific priming effect. This result, however, does not address the question of whether sequential priming is linked to absolute or relative physical attributes because the two were confounded in the earlier studies.

The purpose of the present studies was to further explore the relationship between sequential priming with hierarchical stimuli by focusing on the dissociability of target level from target resolution, or actual target size. Hierarchical stimuli were presented on each trial, and the participants were required to identify a target letter that could appear at either the local or global level. The primary manipulation involved the total size of the stimuli. Two sizes were used with the constraint that the global shape of the smaller stimuli subtended the same visual angle as each of the local elements of the larger stimuli. Examples of these stimuli are shown in Figure 1.

The critical question centered on whether sequential priming effects would be based on similarities in absolute target resolution or whether these effects reflect a more abstract level of representation. On one hand, if target resolution per se is critical, then one would expect to observe intertrial facilitation when successive targets occur at the same absolute size, regardless of whether these targets lie at different levels in the hierarchical organization of the stimulus (e.g., a local target contained in a large stimulus followed by a global target contained in a small stimulus, or vice versa). Alternatively, sequential priming effects may be independent of absolute target resolution, or target size. Priming might be defined in terms of the level, or relative size, at which the target exists regardless of whether the stimulus itself is small or large. If this were the case, sequential priming would be expected when the target appears at the same level on two successive trials. For example, there should be facilitation when the target is at the local level of a small stimulus on trial *N* and at the local level of a large stimulus on trial $N + 1$. Because these two targets contain information at very different resolutions, a mechanism based on such absolute attributes may be inappropriate. Rather, the sequential priming effects could be attributed to a more abstract level of representation, one that goes beyond absolute size and may represent relative size or ordinal level. In all of the previous studies of sequential priming in hierarchical figures, the size of the stimuli was held constant. As such, it was not possible to discriminate between these two hypotheses. For stimulus pairs that yielded sequential priming, the target was at the same level and the same resolution on successive trials. By varying the size of the stimuli, this confound can be eliminated.

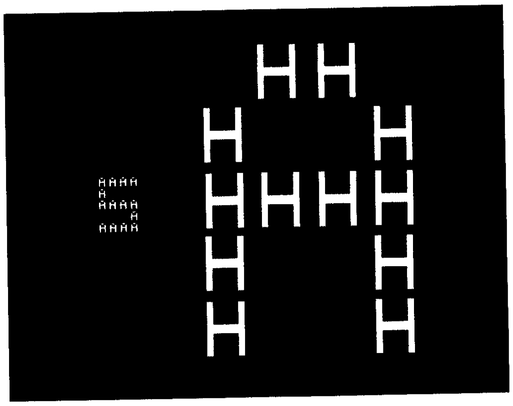

Figure 1. Two examples of the hierarchical stimuli presented in Experiments 1 and 2. Note that the global S in the smaller stimulus subtends the same visual angle as the local H in the larger stimulus (a small-global to large-local sequence).

Experiment 1

To determine whether the critical factor in priming is maintaining the target's resolution in an absolute sense or preserving its hierarchical position within a pattern (level) across trials, we introduced a stimulus size manipulation. Participants were shown hierarchical letter displays that appeared at two possible sizes such that global elements of the smaller figure subtended the same visual angle as local elements of the larger figure. In this way, we equated the particular, absolute target resolution that carried information necessary to identify small-global and large-local targets but varied its relative value. The task was to identify which of two possible target letters appeared in each hierarchical stimulus. The primary dependent variable was RT, and responses were to be made without regard to the level of the target.

If level-specific facilitation can be explained completely in terms of *relative* target resolution, then speed of responding should be faster when target level remains constant across successive trials, irrespective of changes in absolute target resolution. In other words, RT should be faster across trials when the target level is preserved than when it changes, regardless of changes in total stimulus size. If, however, sequential priming is produced by absolute target resolution, then RTs should be faster across trials that share a specific target resolution, irrespective of level.

In Experiment 1b, the stimuli and procedure were identical to that of Experiment 1a except that participants were tested in multiple sessions to increase statistical power sufficiently for an analysis of target-letter repetition, as well as of target level and stimulus size.

Method

Participants. For Experiment 1a, 12 undergraduates from the University of California, Berkeley, participated to fulfill a course requirement. For Experiment 1b, 6 undergraduate students were recruited and paid $6/hr for four sessions. All participants were screened for normal or corrected-to-normal vision prior to participation.

Apparatus. Stimuli were generated on a Samsung Syncmaster3 color monitor, which was controlled by an IBM-compatible 386 computer installed with a video graphics array card. All experimental events were controlled by means of the MicroExperimental Laboratory software package.

Stimuli. The stimuli consisted of 16 hierarchical figures, each containing a combination of one target and one distractor. The target was either a capital H or S, and the distractor was either a capital A or E. For each hierarchical stimulus, a global letter was created by arranging local letters in a 4 × 5 matrix. Twelve local elements were used to create the global shapes of H and A, and 14 local elements were used for the shapes of S and E. Global elements of the large figures measured 9.1 × 14.2 cm and subtended 8.6 × 13.4° of visual angle. Local elements of large stimuli measured 1.50 × 2.45 cm and subtended 1.5 × 2.3° of visual angle, as did global elements of small stimuli. Local elements of small patterns measured 0.30 cm × 0.45 cm, subtending 0.30 × 0.42°. All letters were approximately 1.5 times as tall as they were wide. A star-shaped fixation point had a diameter of 0.20 and subtended about 0.20° of visual angle. Stimuli and the fixation point were presented as white figures on a dark gray background.

All letters had an equal probability of appearing at the global or local level. Thus, each type of target letter and distractor letter appeared on half of the trials. Additionally, the large hierarchical pattern was presented on half of the trials, and the small hierarchical pattern was presented on the remaining trials.

Procedure. Participants were seated in front of a computer screen, centered in front of the monitor and keyboard. A chin rest was used to ensure that their eyes were kept at a constant distance of 60 cm from the screen. Instructions for the task were presented on the computer screen. The instructions informed the participants that they were to identify whether the hierarchical pattern contained an H or an S. Responses were to be made by using the right and left index fingers to press one of two keys on a keyboard. The keys were labeled H and S and were counterbalanced across participants. The participants were informed that they should respond as quickly as possible while attempting to minimize errors.

Once the participants had learned the stimulus–response mappings, a practice block of 24 trials was conducted. Following this, each participant completed three test blocks of 168 trials each. Each of the 16 hierarchical stimuli was presented 10 times in random order during a given block. The proportions of small-local (1/3) and large-global (1/3) targets were double those of either the small-global (1/6) or large-local (1/6) targets. This target distribution was chosen to ensure that all three possible target resolutions as well as sequence types were equally represented across the blocks.[1] The procedure for Experiment 1b was similar except that participants were involved in four sessions rather than in a single session. Each session was conducted on separate days with the constraint that participants complete the study within a 7-day period.

At the start of each trial, the fixation point appeared at the center of the screen for a variable duration ranging from 100 to 500 ms. Participants were instructed to keep their eyes on this location at all times and to use this signal as a cue to prepare for a forthcoming stimulus. The screen was blank for 100 ms after the offset of the fixation point, followed by the presentation of the hierarchical stimulus. The stimulus remained on the screen for 100 ms. Response times were measured from stimulus onset. No feedback was given for incorrect responses. Brief rest periods were provided between successive blocks.

Analysis. An overview of the 16 possible conditions when the trials were considered as pairs, collapsed over the two types of targets, is provided in Table 1. The prime trials are denoted by N, and $N + 1$ refers to the probes. The RT being measured for each cell was that of the probe trial. The abbreviations indicate pairs in which the successive trials involved the same or different stimulus size (SS vs. DS), the same or different target level (SL vs. DL), and the same or different target resolution (SR vs. DR). As outlined earlier, our primary interest was in unconfounding the effects of repeating the target level and target resolution. However, an examination of Table 1 reveals an imbalance in the design. Namely, the target cannot repeat at the same resolution without repeating on other factors for two of the targets: the small-local and large-global conditions (columns 1 and 4).

Given this unavoidable imbalance, the primary analyses were restricted to conditions in which the target on trial $N + 1$ was at the global level for the small stimulus or the local level for the large stimulus (columns 2 and 3). Within these conditions, there were eight types of pairwise relations that constituted a 2 × 2 × 2 factorial design. One factor was the size of the area covered by the hierarchical stimulus on trial $N + 1$ (small or large). The second

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[1] In a pilot version of Experiment 1, the relative distribution of targets at each resolution was skewed such that medium-resolution targets were twice as frequent as small- or large-resolution targets. This imbalance produced an overall, nonsequential effect such that responding to medium-resolution targets was fastest. This effect disappeared when the imbalance in target presentation was corrected. Although interesting, this probability effect was independent and tangential to the main focus of sequential priming effects, and therefore this experiment was omitted from the current report.

Table 1
An Outline of the General Experimental Design

Trial N	Trial $N + 1$			
	Small local	Small global	Large local	Large global
Small local	SS, SL, SR	SS, DL, DR	DS, SL, DR	DS, DL, DR
Small global	SS, DL, DR	SS, SL, SR	DS, DL, SR	DS, SL, DR
Large local	DS, SL, DR	DS, DL, SR	SS, SL, SR	SS, DL, DR
Large global	DS, DL, DR	DS, SL, DR	SS, DL, DR	SS, SL, SR

Note. Row labels indicate whether the target letter on trial N was presented as part of a small or large stimulus and whether the target appeared at the local or global level. Column labels indicate whether the target letter on trial $N + 1$ was presented in a small or large stimulus and whether the target appeared at the local or global level. SS and DS = same and different stimulus size, respectively; SL and DL = same and different target level, respectively; SR and DR = same and different target resolution, respectively.

factor was based on the level relationship (same or different) of the targets on trial N and trial $N + 1$ irrespective of the overall size of the stimulus. The third factor was based on the resolution (same or different) of targets on trial N and trial $N + 1$. Note that total stimulus size could remain the same both when the target level and resolution were the same across successive trials (e.g., small global followed by small global) and when they were both different (e.g., small local followed by small global). In the former case, target level and target resolution were confounded and could both contribute to any observed priming. Because both factors were absent from the latter case, this condition was used as a baseline in our planned comparisons. For each of the experiments, data corresponding to each of the 16 cells shown in Table 1 are provided.

In addition to and preceding the primary analyses for Experiments 1a and 1b, a separate analysis including only those sequences that began and ended in same-size stimuli was performed to determine whether the current experiments replicated the basic finding of level-specific priming as reported in Robertson (1996), independent of the target-level/target-resolution dissociation that was the critical variable tested in the present article. These cells are represented in Table 1 as the left upper four cells and the right bottom four cells (upper left quadrant and lower right quadrant, respectively). These eight cells were partitioned and analyzed according to a 2 × 2 × 2 factorial design. The factors consisted of stimulus size presented on trial $N + 1$ (small or large), target-level relationship between trial N and trial $N + 1$ (same or different), and the relationship between target-letter identities across trial N and trial $N + 1$ (same or different). We also conducted a similar 2 × 2 × 2 design incorporating the factors of stimulus size on trial $N + 1$ (small or large), target-level relationship (same or different), and the relationship between distractor-letter identities across trial N and $N + 1$. We conducted no such preliminary analyses for Experiment 3 because its stimuli and design differed from those of Experiments 1 and 2. For all analyses, only correct responses were used.

Results

Preliminary analyses: Experiment 1a. In the preliminary analysis, a 2 × 2 × 2 repeated measures analysis of variance (ANOVA), with the factors of stimulus size on Trial $N + 1$ (small vs. large), same or different target level (SL vs. DL), and same or different target letter (ST vs. DT), was performed for data cells falling into the upper left and lower right quadrants of Table 2 (upper portion). The main effects for stimulus size and target level were reliable, $F(1, 11) = 10.28, p < .01$, and $F(1, 11) = 19.94, p < .001$, respectively. Participants responded to large stimuli 36-ms faster than to small stimuli. More important, RTs were faster when target level repeated than when target level switched across trials (39 ms). Although it appeared that RTs were faster when target-letter identity changed, rather than repeated, across successive trials (20 ms), this difference was only marginally significant, $F(1, 11) = 4.34, p < .10$.

Although none of the possible two-way or three-way interactions was reliable, we performed planned comparisons to ensure that level-repetition priming had not been constrained by stimulus size or target level on trial $N + 1$. Level-specific facilitation was not differentially affected by $N + 1$ stimulus size ($F < 1$). Sequences comprised of targets successively presented at the local level (local–local) were significantly faster than global–local sequences (30 ms), $F(1, 11) = 31.89, p < .0005$. Similarly, global–global sequences were significantly faster than local–global sequences (52 ms), $F(1, 11) = 18.57, p < .005$.

Finally, a 2 × 2 × 2 analysis incorporating stimulus size (small vs. large), same or different target level (SL vs. DL), and same or different distractor letter (SD vs. DD) was also conducted. There was a trend for an effect of distractor letter such that responses were 18-ms faster when distractor letter was repeated across trials, $F(1, 11) = 3.94, p < .10$. Little can be said about this effect. It was small and did not replicate in any of the other experiments reported in this article or in previous reports that included distractor letter (see Robertson, 1996). Distractor letter did not interact reliably with any other factors.

Primary analyses: Experiment 1a. For the primary analysis for Experiment 1a, a 2 × 2 × 2 ANOVA for repeated measures was performed for the factors: small or large $N + 1$ stimulus (small vs. large), same or different target level (SL vs. DL), and same or different target resolution (SR vs. DR). The relevant cells within the overall 16-cell matrix of means for each of the sequential conditions are presented in the center two columns of Table 2 (upper portion). The factors of target and distractor letter were collapsed to increase statistical power and also because they

Table 2
Mean Median Reaction Times (RTs; in Milliseconds) to Identify Targets for Trial N + 1 as a Function of Trial N and Trial N + 1 Stimulus Properties in Experiments 1a and 1b

	Trial $N + 1$							
	Small local		Small global		Large local		Large global	
Trial *N*	RT	*SD*	RT	*SD*	RT	*SD*	RT	*SD*
	Experiment 1a							
Small local	372	92	438	171	334	95	384	95
	SS, SL, SR		SS, DL, DR		DS, SL, DR		DS, DL, DR	
Small global	404	94	378	154	379	92	359	83
	SS, DL, DR		SS, SL, SR		DS, DL, SR		DS, SL, DR	
Large local	394	110	423	202	330	102	407	107
	DS, SL, DR		DS, DL, SR		SS, SL, SR		SS, DL, DR	
Large global	409	99	372	150	357	115	363	95
	DS, DL, DR		DS, SL, DR		SS, DL, DR		SS, SL, SR	
	Experiment 1b							
Small local	306	52	354	93	280	50	320	62
	SS, SL, SR		SS, DL, DR		DS, SL, DR		DS, DL, DR	
Small global	324	59	309	69	304	63	316	55
	SS, DL, DR		SS, SL, SR		DS, DL, SR		DS, SL, DR	
Large local	319	52	343	72	274	50	328	66
	DS, SL, DR		DS, DL, SR		SS, SL, SR		SS, DL, DR	
Large global	342	58	310	49	290	59	315	53
	DS, DL, DR		DS, SL, DR		SS, DL, DR		SS, SL, SR	

Note. SS and DS = same and different stimulus size, respectively; SL and DL = same and different target level, respectively; SR and DR = same and different target resolution, respectively.

had little effect on level-specific priming across all experiments.

Same-level sequences were faster than different-level sequences by 46 ms, $F(1, 11) = 13.30, p < .005$. There was no main effect of target resolution ($F < 1$). Likewise, the effect of total stimulus size was not reliable, $F(1, 11) = 3.05$, $p > .10$. Neither the interaction between stimulus size and target level, $F(1, 11) = 1.21, p > .10$, nor between stimulus size and target resolution ($F < 1$) was significant. Similarly, the interaction between target level and target resolution was not significant ($F < 1$). Finally, there was no evidence of a three-way interaction ($F < 1$).[2]

Given the lack of an effect of stimulus size, the data were collapsed over this factor for the planned comparisons (see Figure 2). A comparison of response latencies between sequences in which only target level was repeated (DS, SL, DR) versus the baseline condition in which both the target level and target resolution were altered (SS, DL, DR) revealed that RTs to the former were 45-ms faster, $F(1, 11) = 5.97$, $p < .05$. Conversely, sequences across which only target resolution was preserved (DS, DL, SR) were not significantly different from baseline responding ($F < 1$). Comparison of sequences in which all three factors remained constant (SS, SL, SR) across trials again revealed significantly faster responses (44 ms) over the baseline condition (SS, DL, DR), $F(1, 11) = 5.81, p < .05$.

We also conducted planned comparisons that incorporated the factor of stimulus size on trial $N + 1$. This more focused analysis revealed that the level-mediated priming effect was indeed only significant for sequences ending in small stimuli, that is, when the target remained at the global level. For this condition, the level-specific priming effect was 66 ms, $F(1, 11) = 6.55$, $p < .05$. In contrast, the effect was reduced to a nonsignificant 23 ms for those sequences ending in a large stimulus on trial $N + 1$, that is, when the target remained at the local level ($F < 1$). This asymmetry was also confirmed when additional comparisons were performed on the relevant cells involving small-local (SS, DL, DR) and large-global (DS, SL, DR) targets on trial $N + 1$ (10 ms, $F < 1$, vs. 48 ms, $F[1, 11] = 16.93$, $p < .005$, respectively).

We next performed a 2 × 2 ANOVA for all of the data for

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[2] Despite the reduction in statistical power produced by the addition of another factor to the current design, for the sake of completeness we performed a 2 × 2 × 2 × 2 repeated measures ANOVA that also incorporated same or different target-letter identity with the stimulus size, target level, and target spatial frequency. The preliminary analyses had been predictive: When target letter changed across trials, responding was facilitated (48 ms). This factor did not interact with stimulus size, target level, or target spatial frequency. The analogous analysis incorporating distractor letter as the additional factor also closely resembled the findings of the preliminary analysis. Distractor-letter repetition across trials had no effect in itself and also did not interact with these three other factors.

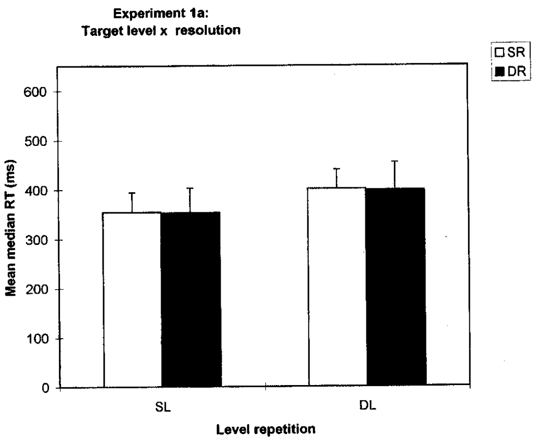

Figure 2. Experiment 1a: Mean median reaction time (RT) as a function of target level and target resolution repetition across successive trials. SL and DL = same and different target level, respectively; SR and DR = same and different target resolution, respectively.

the nonsequential factors of stimulus size on trial $N + 1$ (small vs. large) and target level on trial $N + 1$ (local vs. global) to assess the overall effects of our variables. Stimulus size produced a significant main effect: RTs to large stimuli were faster than RTs to small stimuli by 35 ms, $F(1, 11) = 5.81, p < .05$. The effect of level, however, was not significant, $F(1, 11) = 1.03$, $p > .10$, nor was the interaction, $F(1, 11) < 1$ (small local: 395 ms, $SD = 96$; small global: 403 ms, $SD = 164$; large local: 350 ms, $SD = 92$; large global: 378 ms, $SD = 94$). Planned comparisons indicated that RTs to small-local targets (smallest target resolution) and small-global targets (medium target resolution) were statistically indistinguishable ($F < 1$). Similarly, there was no difference, $F(1, 11) = 2.08, p > .10$, between responding to large-global targets (largest target resolution) and large local targets (medium target resolution). Because target resolution is defined by particular combinations of stimulus size and target level, this analysis also demonstrates that there was no evidence of an overall global or local precedence effect for either small or large stimuli.

Mean error rate was 3.8%. There was no statistical evidence for a speed–accuracy trade-off, nor was there a reliable effect of sequence type on errors.

Preliminary analyses: Experiment 1b. As before, the preliminary analyses of Experiment 1b involved only those cells in which stimulus size remained constant across successive trials (upper left and lower right quadrants of Table 2, lower portion) and included the factors of stimulus size on trial $N + 1$ (small vs. large), same or different target level (SL vs. DL), and same or different target letter (ST vs. DT). There was a main effect of stimulus size such that participants responded to large stimuli faster (22 ms) than to small stimuli. Additionally, RTs were facilitated when target level repeated across trials, $F(1, 11) = 6.40$, $p < .05$. Repeating target letter had no effect ($F < 1$). Of the possible two-way or three-way interactions, only the interaction between stimulus size and target letter was significant, $F(1, 11) = 17.69, p < .01$. For the latter, when trial $N + 1$ involved a small stimulus, there was a marginally significant effect such that changing target letter across trials decreased response time by 8 ms, $F(1, 11) = 5.25, p < .10$. This trend was consistent with the other experiments reported in this article. Conversely, unlike the other experiments, this effect reversed for successive trials ending in large (trial $N + 1$) stimuli; changing target letter now slowed response latency by 13 ms, $F(1, 11) = 13.38, p < .05$. The latter was a small effect that did not replicate in any of the other experiments, and as it was tangential to the main issues addressed in the article, it is not discussed further.

Primary analyses: Experiment 1b. For the primary analyses of Experiment 1b, the basic statistical design was enlarged to encompass the additional factor of whether the target letter was the same or different (ST vs. DT). This change allowed us to directly investigate possible interactions between level-mediated priming and effects of target- and distractor-letter repetition across sequences of trials. Same-level sequences were 32 ms faster than different-level sequences, $F(1, 5) = 10.88$, $p < .05$ (see Figure 3). Moreover, the effect of stimulus size was now significant, because RTs were faster by 44 ms to large-local targets compared with small-global targets, $F(1, 5) = 6.67, p < .05$. Repeating target resolution did not produce a reliable effect on response latencies ($F < 1$), and there was no effect of target-letter repetition ($F < 1$). That is, irrespective of variations in target level or resolution, there was no advantage over successive trials when the target identity remained

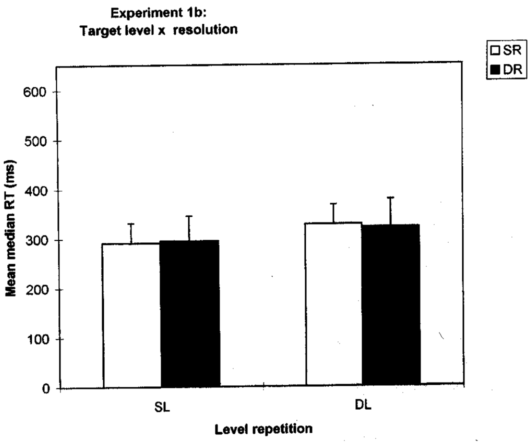

Figure 3. Experiment 1b: Mean median reaction time (RT) as a function of target level and target resolution repetition across successive trials. SL and DL = same and different target level, respectively; SR and DR = same and different target resolution, respectively.

the same. None of the two-way or three-way interactions reached significance, nor was there any statistical support for the four-way interaction ($F < 1$).

To examine the possible contribution of distractor-letter repetition to the priming effect, the preceding $2 \times 2 \times 2 \times 2$ analysis was repeated, but the fourth factor was whether the distractor letter was the same or different (SD vs. DD). There was no evidence of a main effect of distractor-letter repetition, and this factor did not interact with any of the other variables ($F < 1$). A more restricted analysis limited to those trials in which the target on successive trials was at the same level and of the same resolution also revealed that there was no effect of repeating either target or distractor identity. Thus, repetition priming for target or distractor shape or identity was not evident. The means are given in Table 2 (lower portion).

The data were collapsed over stimulus size, target-letter identity, and distractor-letter identity, and as in Experiment 1a, planned comparisons for level-repetition sequences (DS, SL, DR) versus the baseline (SS, DL, DR) condition were performed. When target level repeated, RT was significantly faster by 26 ms, $F(1, 5) = 8.46, p < .05$. Repetition of target resolution (DS, DL, SR), however, did not produce any change from baseline responding ($F < 1$). Finally, comparison of sequences in which both target level and resolution repeated (SS, SL, SR) versus the baseline condition (SS, DL, DR) revealed that the former was significantly faster by 31 ms, $F(1, 5) = 11.68, p < .05$.

The level-specific priming effect was again found to be restricted to conditions in which the target remained at the global level in a series of planned comparisons limited to the cells used in the primary analyses, $F(1, 11) = 11.24, p < .05$. Unlike in Experiment 1a, the level-specific priming effect was not reliable for comparisons based on RTs to small-local and large-global targets, $F(1, 11) = 2.40, p > .10$.

A 2×2 ANOVA for all of the data for the nonsequential factors, stimulus size on trial $N + 1$ (small vs. large), and target level on trial $N + 1$ (local vs. global) showed that participants responded faster to local targets in large stimuli compared with local targets in small stimuli, $F(1, 5) = 18.79, p < .005$ (advantage of 23 ms). The overall effect of level, however, was not significant, $F(1, 5) = 2.31, p > .10$, nor was the interaction, $F(1, 5) = 3.96, p > .10$. Planned comparisons showed no significant differences in RTs to small-local and small-global targets ($F < 1$). However, large-local targets were identified more quickly than large-global targets, $F(1, 5) = 12.73, p < .05$ (large local: 287 ms, $SD = 52$; large global: 319 ms, $SD = 52$). Another way of stating the latter result is that for large stimuli, there was local precedence, whereas neither level was favored overall for small stimuli.

Error analysis did not reveal a speed–accuracy trade-off; overall error rate was 4.1%. There was no effect of sequence type on error rate.

Discussion

The preliminary analyses for Experiments 1a and 1b replicated previously reported findings of level-specific priming: Sequential priming effects occur when the target is at the same level on successive trials. There was no evidence in favor of a sequential priming effect related to target resolution alone. As such, the results favor a hypothesis in which sequential priming reflects an abstract level of representation in terms of the relative scale of information in hierarchical patterns.

However, in both Experiments 1a and 1b, level-specific priming was found to occur exclusively for sequences ending in global $N + 1$ targets (although the means for $N + 1$ local targets were in the expected direction) when stimulus size changed across trials (primary analyses). This asymmetry was not observed when stimulus size across consecutive trials did not shift (preliminary analyses). Thus, although priming is not mediated by target resolution per se, we found that changing stimulus size does alter the effect. This contrasts with previous findings that involved no stimulus-size manipulation and that demonstrated equal amounts of level-specific priming for local–local sequences as well as global–global sequences (Robertson, 1996; Robertson et al., 1993; Ward, 1982). It is not clear why level priming remained strong for global–global sequences across changes in stimulus size and not for local–local sequences. It may reflect the dual function of the global level in defining both a level and the overall size of the stimulus. In an experiment in which size randomly changes from trial to trial, the role of the global level to act as a size anchor may produce priming for a different reason than when the stimulus size does not change from trial to trial. In Experiment 2 we explored further the question of how manipulating total spatial extent of stimuli may affect sequential, level-mediated priming by including a frame to act as a size anchor on every trial.

Additionally, the primary analysis of Experiment 1b provided direct evidence that the level-mediated priming effect is independent of target identity or shape, a result in accord with Robertson (1996). If anything, repeating target letter seemed to slow RT both in Robertson's (1996) study and in the current experiments. Similarly, response latencies were unaffected by whether the distractor identity was held constant or varied. These results reinforce the hypothesis that the critical factor underlying sequential priming for hierarchical figures is the relatively abstract factor of level, independent of the particular physical form of the target.

Experiment 2

In the previous two experiments, sequential priming effects were shown to occur as a result of repeating a target at the same level rather than of repeating target resolution. We were able to unconfound these factors by introducing a manipulation of total stimulus size. However, this manipulation not only separated target level from target resolution, it also changed the total spatial extent of the stimulus. The large stimuli extended over a larger portion of the screen than did the smaller stimuli. Contrasting level-repetition effects observed in the preliminary as opposed to the primary analyses of Experiments 1 and 2 indicated that changing stimulus size across successive trials had an effect

Table 3
Mean Median Reaction Times (RTs; in Milliseconds) to Identify Targets for Trial N + 1 as a Function of Trial N and Trial N + 1 Stimulus Properties in Experiment 2

	Trial $N + 1$							
	Small local		Small global		Large local		Large global	
Trial *N*	RT	*SD*	RT	*SD*	RT	*SD*	RT	*SD*
Small local	482	206	552	279	444	186	508	183
	SS, SL, SR		SS, DL, DR		DS, SL, DR		DS, DL, DR	
Small global	523	209	448	206	494	216	475	191
	SS, DL, DR		SS, SL, SR		DS, DL, SR		DS, SL, DR	
Large local	521	212	486	281	424	189	516	208
	DS, SL, DR		DS, DL, SR		SS, SL, SR		SS, DL, DR	
Large global	583	280	460	203	515	281	447	143
	DS, DL, DR		DS, SL, DR		SS, DL, DR		SS, SL, SR	

Note. SS and DS = same and different stimulus size, respectively; SL and DL = same and different target level, respectively; SR and DR = same and different target resolution, respectively.

on priming such that only global–global sequences were facilitated. The uncertainty introduced by this manipulation could have obscured target-level or resolution effects that were actually present. To investigate this issue further, we needed to design stimuli that would cover the same area on the computer screen on each trial while keeping target-level/target-resolution dissociation intact. Thus, in Experiment 2 we modified the procedure so that a frame of a constant size surrounded and was presented in synchrony with the onset and offset of the hierarchical figures. (In this way, the frame was part of the whole display on each trial and different from other constant frames in the environment such as the perimeter of the computer monitor.) As stated, we introduced this change in an attempt to ensure that the stimulus extended over the same region on all trials. However, we also chose this particular change because it allowed us to manipulate stimulus spatial extent without introducing an additional variable. Although the frame equalized spatial extent, it did not contain information relevant to the letter-identification task that we asked participants to perform.

Method

Participants. Twelve undergraduates from the University of California, Berkeley, participated to fulfill a course requirement. Again, all the students were screened for normal or corrected-to-normal vision.

Apparatus. The apparatus used in Experiment 2 was identical to that used in Experiments 1a and 1b.

Stimuli. The stimuli were identical to those used in Experiment 1 except that they now also included a white frame that appeared simultaneously with the hierarchical stimulus. The frame was 10 × 15 cm, subtending 9.5 × 14.2° of visual angle, and was centered around the hierarchical letters.

Procedure. Except for the addition of a frame into the stimuli, the procedure of Experiment 2 was the same as that of Experiment 1a. Rates and times of presentation were the same.

Results

Preliminary analyses. The data for Experiment 2 are summarized in Table 3. The preliminary analysis for Experiment 2, involving small or large hierarchical stimulus size on trial $N + 1$ (small vs. large), same or different target level (SL vs. DL), and same or different target letter (ST vs. DT), revealed neither a main effect of target letter nor any evidence of interactions including this factor. There was a significant effect of target level such that responses were faster when target level remained the same, $F(1, 11) = 10.04, p < .01$. Similarly, a repeated measures ANOVA for the factors of hierarchical stimulus size, target level, and same or different distractor letter showed that distractor-letter repetition across trials had no reliable effects. Because neither target-letter nor distractor-letter repetition was found to have any effect, we collapsed over these factors in the main analysis.

Though none of the two-way or three-way interactions was reliable, we performed planned comparisons to ensure that level-repetition priming was not influenced by the size of the hierarchical stimulus itself or by the particular level of the target on trial $N + 1$. The size of the hierarchical stimulus alone was not affected by $N + 1$ target resolution ($F < 1$). Similarly, both local–local and global–global sequences were significantly faster than global–local (66 ms) and local–global (84 ms) sequences Fs(1, 11) = 51.77 and 87.56, respectively, ps < .0005.

Primary analyses. For the primary analysis, consistent with Experiments 1a and 1b, same-level sequences were faster by 68 ms than were different-level sequences, $F(1, 11) = 7.47, p < .05$. There was a trend toward an effect of target resolution, $F(1, 11) = 3.31, p < .10$. The effect of hierarchical pattern size was not reliable ($F < 1$), nor were any of the interactions.[3]

Collapsed over hierarchical stimulus size, planned com-

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[3] When target and distractor identity were incorporated into the main analyses, as in the previous experiments, neither factor reliably interacted with stimulus size, target level, or target spatial frequency. Likewise, none of the higher order interactions was significant. Similarly, there was no main effect of target-letter or distractor-letter repetition across successive trials ($F < 1$).

parisons for sequences in which target level repeated while target resolution changed (DS, SL, DR) versus the baseline condition in which both factors changed (SS, DL, DR) revealed that the former were significantly faster by 81 ms, $F(1, 11) = 24.39$, $p < .0005$. Unlike the previous experiments, repeating target resolution alone (DS, DL, SR) also produced significant priming of 43 ms relative to the same baseline, $F(1, 11) = 6.84$, $p < .05$. Finally, repeating both factors (SS, SL, SR) produced reliable facilitation, $F(1, 11) = 35.01$, $p < .0005$. The data are shown in Figure 4.

As in the previous experiments, to assess whether target resolution might affect responses overall rather than exert a sequential effect, we performed a 2 × 2 ANOVA for the factors of hierarchical stimulus size (small vs. large) and target level (local vs. global) for all of the data. The pattern of results was similar to that obtained in Experiment 1. The main effect of hierarchical stimulus size was significant, $F(1, 11) = 7.45$, $p < .05$. Neither the main effect of target level nor the interaction between the factors was significant ($F < 1$).

Planned comparisons between the cells of the ANOVA showed that speed of responding to small-local (i.e., smallest resolution) targets (527 ms, $SD = 224$) was not significantly different from responses to large-global (i.e., largest resolution) targets (486 ms, $SD = 180$), $F(1, 11) = 3.03$, $p > .10$. Small-local targets were not statistically different from small-global (i.e., medium resolution) targets (517 ms, $SD = 254$, $F < 1$), nor were large-global targets distinguishable from large-local (i.e., medium resolution) targets (469 ms, $SD = 211$, $F < 1$).

Planned comparisons for sequences ending in a small hierarchical stimulus and in which target level remained constant while target resolution changed versus the baseline condition (in which both factors changed) showed that maintaining target level across trials facilitated response times by 92 ms, $F(1, 11) = 15.52$, $p < .005$. Unlike the previous experiments, sequences in which target resolution repeated compared with the baseline condition also revealed a 66-ms significant difference, $F(1, 11) = 7.89$, $p < .05$.

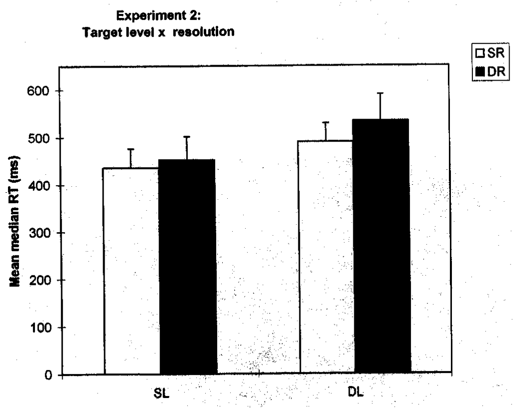

Figure 4. Experiment 2: Mean median reaction time (RT) as a function of target level and target resolution repetition across successive trials. All stimuli incorporated a frame around the hierarchical letter figures. SL and DL = same and different target level, respectively; SR and DR = same and different target resolution, respectively.

Similar comparisons conducted for sequences with a large hierarchical stimulus presented during trial $N + 1$ revealed that repeating target level alone was reliably faster than the corresponding baseline condition (71 ms), $F(1, 11) = 9.27$, $p < .05$. Repeating target resolution alone did not, however, significantly speed responses relative to the same baseline condition (21 ms, $F < 1$).

Mean error rate was 4.6%. There was no reliable effect of sequence condition on error rate, and error analysis did not reveal evidence for a speed–accuracy trade-off.

Discussion

As in Experiments 1a and 1b, target-level priming was strongly supported. Sequences in which target level was repeated showed the greatest amount of RT facilitation. It seems that in the course of responding, participants selectively direct attention to a particular level of the hierarchical stimulus and that the activation that accompanies this process persists into the next trial. However, the results of this experiment differed in one important respect from those obtained in the preceding experiments. Experiment 2 showed that there is also a sequential effect of target resolution when the overall stimuli are equated in terms of total spatial extent by means of the addition of a simple frame. That is, there appears to be a priming effect: RTs are facilitated when the target is contained at the same resolution on successive trials, even when this involves a change in target level.

The latter finding is particularly interesting because it addresses, albeit indirectly, the possible locus of level-mediated facilitation in perceptual processing. As currently characterized, sequential priming has been determined to occur at a postsensory, yet relatively early, preattentive stage of processing. The notion that priming is mediated by a postsensory mechanism is drawn from the observation that priming is long lasting (at least to 3 s) between consecutive trials, far beyond the life span of an iconic trace and is robust even when the stimulus changes location within the display (Robertson, 1996; Ward, 1982). Also, studies of an analogous form of intertrial facilitation based on target color rather than on target level and involving visual search demonstrated that priming transfers not only between visual fields but also interocularly (Maljkovic & Nakayama, 1994).

It is also reasonable to assume that this type of level-mediated effect occurs relatively early in the perceptual stream, because our experiments as well as previous studies have found little evidence to suggest that concomitant features such as the shape or identities of stimulus letters affect level priming. Neither location nor identity priming can account for level priming. Within the domain of visual search, Maljkovic and Nakayama (1994) likewise found intertrial priming for repeated target color and spatial frequency that persisted across changes in stimulus location, response, and shape. As in our study, this priming occurred despite the fact that color and spatial frequency were irrelevant to the actual response (e.g., form discrimination) required (see also Maljkovic & Nakayama, 1994). Similarly, Muller, Heller, and Ziegler (1995) reported intertrial priming by means of a visual search paradigm, but only in cases in which successive targets were defined within a given dimension (e.g., orientation) rather than across different dimensions (e.g., orientation and color).

Given these findings, in the present study one might expect the addition of a frame to affect performance despite the fact that it is completely task irrelevant (in the sense that it should not aid in the parsing of distractor letters from target letters and also has no response associated with it) either because it adds an additional level of complexity to the display that helps define each level of the hierarchical pattern more precisely or because it creates overall size certainty and reduces noise. The frame could be characterized as occupying a level in itself, relative to the letter pattern. The resolution of the targets relative to the frame are well-defined. Relative resolution need not be calculated only with reference to the two levels themselves as was required in Experiments 1a and 1b. They can now be calculated relative to the frame size or "frame level." Under these conditions, resolution does produce priming. The fact, however, that purely level-mediated priming is still observed suggests that the level effect also involves other stages in which levels are parsed according to the relative resolution of the global and local levels in a hierarchical pattern. This characterization is consistent not only with the present data but with existing models of sequential dimensional priming based on spatial frequency (Robertson, 1996).

One interesting avenue for further investigation of early versus later influences of sequential priming is to determine whether particular presentation conditions affect the way that irrelevant components such as a frame influence priming. If irrelevant components can be made more discriminable as such to participants, their part in the initial parsing of stimulus displays may be mitigated. The frame in the current experiment, for example, may exert less of an effect if its onset and offset are made asynchronous with the presentation of the hierarchical patterns or if it is presented in a different color than the hierarchical elements.

Experiment 3

The results of Experiment 2 suggested that repetition of target resolution can produce sequential priming when a frame of a constant size surrounds and is presented synchronously with the hierarchical letter stimuli. The inclusion of a frame was not part of the hierarchical letter pattern per se, yet it influenced sequential priming so that target resolution, in addition to level, became important. In the final experiment, we adopted an alternative strategy to more directly equate the spatial extent of the hierarchical letter stimuli themselves. For this purpose, we developed three-tiered hierarchical stimuli.

For these stimuli, an irrelevant level was created by the inclusion of rectangles as part of the hierarchical figure (see Figure 5). For the small-size stimuli, a series of local–global objects were arranged in a large rectangle. For the large-size stimuli, each of the local elements comprised a series of small rectangles. In this manner, the patterns extended over the same spatial extent for both the small and large hierarchical letter stimuli used in the previous experiments. In Experiment 4, the irrelevant rectangles were integral with the local and global letter components critical to performing the identification task. If, as in Experiment 2, level-specific priming involves not only the registration of stimulus features but also the process of parsing relevant from irrelevant components, then one would expect to see a much greater effect of target-resolution repetition than level repetition. As in Experiment 2, the additional information was still irrelevant but was now much more difficult to distinguish as such because it consisted of letterlike shapes and was incorporated into the hierarchical figures themselves.

Method

Participants. Twelve undergraduates from the University of California, Berkeley, received credit toward a departmental requirement for participation. Again, all participants were screened for normal or corrected-to-normal vision.

Apparatus. The apparatus was identical to that used in the previous experiments.

Stimuli. The hierarchical figures shown previously were altered by adding a response-irrelevant rectangle shape at either the smallest or largest possible target resolutions: Figures classified as "small" in Experiments 1 and 2 were embedded in a single large rectangle whose outer contour spanned the same visual angle as that covered by stimuli classified as "large" in the preceding experiments. Conversely, local components of stimuli that had previously been classified as "large" now comprised 12 or 14 small rectangles corresponding in visual angle to the local components of previously classified "small" stimuli (see Figure 5).

Procedure. Except for the change to the stimuli shown in the hierarchical figures, the procedure of Experiment 3 was the same as that of Experiments 1 and 2.

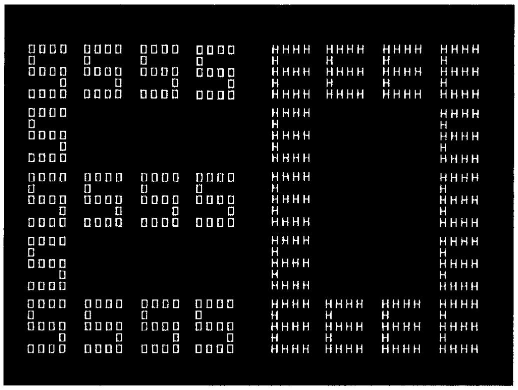

Figure 5. Example of the three-tiered hierarchical stimuli used in Experiment 4.

Table 4
Mean Median Reaction Times (RTs; in Milliseconds) to Identify Targets on Trial N + 1 as a Function of Trial N and Trial N + 1 Stimulus Properties in Experiment 3

	Trial $N + 1$							
	Small local		Small global		Large local		Large global	
Trial N	RT	*SD*	RT	*SD*	RT	*SD*	RT	*SD*
Small local	647 SS, SL, SR	186	439 SS, DL, DR	102	454 DS, SL, DR	125	507 DS, DL, DR	155
Small global	665 SS, DL, DR	168	407 SS, SL, SR	104	408 DS, DL, SR	121	503 DS, SL, DR	135
Large local	650 DS, SL, DR	196	417 DS, DL, SR	140	410 SS, SL, SR	86	502 SS, DL, DR	164
Large global	722 DS, DL, DR	231	428 DS, SL, DR	101	479 SS, DL, DR	126	442 SS, SL, SR	123

Note. SS and DS = same and different stimulus size respectively, relative to the hierarchical letter figure; SL and DL = same and different target-level size, respectively, relative to the hierarchical letter figure; SR and DR = same and different target resolution, respectively.

Results

Primary analyses. As before, the primary analysis was constrained to those sequences of trials with medium-resolution targets on trial $N + 1$ (these cell means are represented in the middle two columns of Table 4). A 2 × 2 × 2 ANOVA for repeated measures was conducted for "stimulus size" for trial $N + 1$ ("small" vs. "large"), same or different "target level" ("SL" vs. "DL"), and same or different target resolution (SR vs. DR). Note that "stimulus size" and "target level" were defined by the extent and relationship between the target and distractor letters previously without regard to the filler shape. As in Experiments 1 and 2, target resolution was defined by the absolute size of the "H" or "S" present in each stimulus, and target level was defined by the relative size of the "H" and "S" in each stimulus. The data, partitioned according to the 16-cell matrix used previously, are shown in Table 4.[4]

In a sharp departure from prior patterns of reported results in this article, there was no main effect of target "level" on speed of responding across successive trials ($F < 1$). There was, however, a reliable main effect of target resolution, $F(1, 11) = 10.90$, $p < .005$. Specifically, for same target-resolution sequences, RT was facilitated by 41 ms relative to different target-resolution sequences. Not surprisingly, the main effect of "stimulus size" was not reliable, $F(1, 11) = 2.11$, $p > .10$. Priming appeared to be greater in magnitude for "large" $N + 1$ stimulus size (71 ms) than for "small" $N + 1$ stimuli (22 ms), but this difference was not significant, $F(1, 11) = 3.27$, $p < .10$. There was no statistical support for any of the other interactions ($F < 1$).

Again, planned comparisons between sequence types in which target "level" was preserved across consecutive trials ("DS," "SL," DR) versus those in which both factors changed ("SS," "DL," DR) were conducted with the data collapsed over the factor of "stimulus size." Unlike the other experiments, there was no significant difference, $F(1, 11) = 1.69$, $p > .10$. When target resolution was repeated ("DS," "DL," SR), responding was reliably facilitated, $F(1, 11) = 11.25$, $p < .001$. Finally, sequences in which both target "level" and target resolution were maintained across successive trials were significantly faster than the baseline condition by 51 ms, $F(1, 11) = 13.24$, $p < .005$. These results are illustrated in Figure 6.

The above analysis might just as well have been conducted as a two-way ANOVA in which "stimulus size" and target resolution were used as factors, because target "level" was only meaningful if the filler shape was disregarded. Although such an approach would have undoubtedly been simpler, we conducted the analysis in this manner to illustrate that participants did incorporate and treat the fillers as part of the stimulus complex—as additional distractors—in much the same way as the "A" and "E" letters were treated. For this reason, the preliminary analysis reported in the previous experiments was unnecessary. This logic applies to the analysis below as well.

Analysis of all the sequences, partitioned into groups according to "stimulus size" and target "level" on trial $N + 1$, was again conducted. Pairwise comparisons revealed that trials containing "small-local" (smallest resolution) targets (671 ms, $SD = 187$) were significantly slower than those with "large-global" (largest resolution) targets (488 ms, $SD = 141$), $F(1, 11) = 30.60$, $p < .0005$. "Small-local" targets were also significantly slower than "small-global" (medium resolution) targets (423 ms, $SD = 102$), $F(1, 11) = 56.54$, $p < .0001$. "Large-global" (largest resolution) targets, however, were not reliably different from "large local" (medium resolution) targets (437 ms, $SD = 110$), $F(1, 11) = 2.37$, $p > .10$.

Discussion

In this study, we added an irrelevant shape so that the whole stimulus subtended the same area on each trial in a way that decreased the distinguishability of the additional

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[4] When the primary analysis was altered to include target-letter repetition or distractor-letter repetition, no main effect of either factor was found ($F < 1$). Likewise, none of the higher order interactions approached significance ($F < 1$).

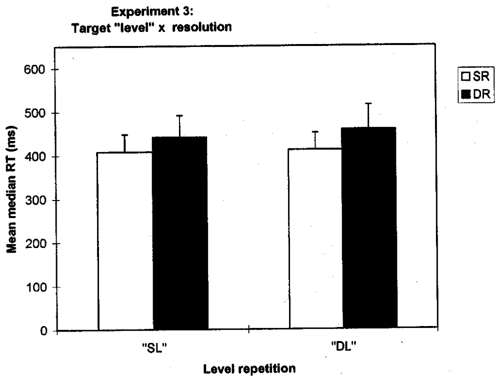

Figure 6. Experiment 3: Mean median reaction time (RT) as a function of "target level" and target resolution repetition across successive trials. "SL" and "DL" = same and different target "level," respectively; SR and DR = same and different target resolution, respectively.

irrelevant information (relative to the frame stimuli used in Experiment 2) by incorporating letterlike components instead of a simple frame. This manipulation had the effect of rendering target-level information as previously defined in a two-level stimulus with a variable target and distractor letter at each level essentially ineffective for target identification. In other words, it appears that participants processed the filler shape as an additional distractor level that, in effect, added a third tier to the two-level hierarchical stimuli used in Experiment 1. These changes, in turn, appear to have favored target resolution, which became the critical parameter in mediating sequential priming.

The results are consistent with those of Experiment 2, which indicated that level-specific priming involves not only the registration of stimulus features but also the process of parsing relevant from irrelevant components. Both target level and resolution were used in identification of the target. In effect, by means of the stimulus changes introduced in Experiment 3, we eliminated the difference between target level and target resolution. That is, there was a three-level stimulus on every trial.

Interestingly, the addition of a third level also produced an overall RT advantage for the medium-resolution targets over both the small- and large-resolution targets. An explanation may be that when target resolution per se becomes the critical parameter in producing sequential priming, participants develop a strategy in which more attention is allocated to an intermediate scale. When targets at either of the extreme resolutions appear, the cost of altering the scope of attention to accommodate target identification at a resolution one step larger or smaller is relatively minimized compared with shifts that would have to span two-step increments.

General Discussion

The experiments in this article were designed to test two alternative hypotheses of sequential priming effects in the identification of targets in hierarchical stimuli. Previous research on this subject had not orthogonally varied target level and target resolution, making it difficult to know if one or both factors were important in level priming. By varying the size of the whole stimulus, we were able to compare the relative contribution of these two factors. Overall, the results indicate that either or both factors can contribute to sequential priming but will do so under different conditions. They also demonstrate that both factors are independent of identity or shape and therefore cannot be attributed to object priming per se. When the range of absolute target resolutions was not held constant across trials, sequential priming occurred when the target appeared at the same level on successive trials, independent of changes in target resolution. However, when the range of candidate target resolutions across the entire stimulus pattern was held constant, as in Experiment 3, sequential priming was related to target resolution even when target "level" changed within a frame that defined the same absolute stimulus size across trials. Experiment 2 demonstrated that changes in the spatial extent of stimuli produced priming for both target resolution and target level.

Evidence for level-specific sequential priming was obtained in all three experiments, although the effect was significant in Experiment 1 for global targets only. Identifying a global target letter on trial N decreased identification time for a global target on trial $N + 1$. Significant level-specific (global and local) priming was observed in Experiment 2. In Experiments 1a, 1b, and 2, this effect occurred even if the actual resolution of the target letters changed from one trial to the next. Conversely, RT was slowed if the target on the preceding trial had appeared at the opposite level even if both letters were the same physical resolution. The critical difference may be that in Experiment 1 (the primary analyses), the stimuli changed in size from trial to trial, whereas in the other experiments, the displays were of constant size. This size uncertainty may produce a dual role for the global level of the hierarchical stimulus—as comprising the global element per se and as defining the overall size of the display. This finding is somewhat consistent with the results of Experiment 2 in that the frame used in this experiment may also have played an early role in processing as a size "anchor" even though it was irrelevant to the task itself.

It is also interesting that precedence effects (Navon, 1977; Navon & Norman, 1983; see also Ward, 1982) cannot account in any simple way for the sequential effects described in this study. The latter part of the primary analyses revealed that there were no overall effects of either global or local precedence for either the small or the large hierarchical patterns except in the case of large hierarchical patterns in Experiment 1b (local precedence observed). We may speculate that the changes in stimulus size used in our study added a level of complexity that made it difficult to examine the possible relationship between precedence and sequential priming. A better way to investigate the connection may be to conduct a study in which there is blocked presentation of stimuli of different sizes that have been found to favor either overall global precedence or overall local precedence (e.g., Lamb & Robertson, 1990; Navon &

Norman, 1983). It would be interesting to see if there are corresponding asymmetries in the magnitude of sequential effects.

Experiments 2 and 3 indicated that priming can also occur for particular target resolutions. Priming was only manifest when the spatial extent of the displays as a whole was held constant across variation in the size of the hierarchical letter pattern. In both experiments, this range was equated by adding irrelevant, nonletter (Experiment 2) or nontarget (Experiment 3) information. When the rectangular outer frame was added in Experiment 2, both level-specific and resolution-specific effects were found. In Experiment 3, the level-specific effects were abolished by the inclusion of the rectangles as the smallest or largest candidate target resolution. With these patterns, it appears that participants did not establish two levels of information. Rather, they were forced to treat each stimulus as comprising three levels of information. A large-global target on trial *N* was not at the same level as a small-global target on trial $N + 1$, because the large rectangle in the latter case now occupied the largest level. Nonetheless, sequential priming did not disappear in this experiment. Rather, it was now evident in terms of resolution-specific priming: Response times were facilitated when the target spanned the same size on successive trials. Relative size was no longer effective.

These results suggest that there are different mechanisms that can modulate sequential priming in part–whole stimuli. One may be involved in parsing stimuli, perhaps on the basis of relative size or resolution, and selectively attending to stimulus level rather than the absolute size, or resolution, of that level. The second might carry out similar functions based on absolute physical target resolution rather than on hierarchical position. Because local components, or details in visual objects, normally comprise smaller elements and global components normally comprise larger elements in complex figures, it might be difficult to detect differential functioning of such systems in normal participants. However, the dissociation between these two mechanisms has received support from neuropsychological research. Lamb, Robertson, and Knight (1990) have reported that patients with damage to the left superior temporal gyrus in the area of the temporal–parietal junction are relatively insensitive to changes in absolute size in identifying a target in multileveled figures and are biased toward the global form over large changes in its size. Patients with damage to a similar area on the right are also relatively insensitive to absolute size but are biased toward the local form. These groups of patients respond to the relative values. Conversely, patients with damage in more dorsal areas in parietal cortex show reduced and sometimes no sequential priming effects even when the stimuli do not change size across trials (as in Experiment 3). It may therefore be instructive to test these groups of patients in a task similar to those used in this article to determine whether component level and resolution can be functionally separated with damage to different areas of the human brain.

Suppose the effects of level- and resolution-based priming occur at different stages. When the stimulus appears, there is an initial, fast assessment of the range of resolution information, with attention initially focused at that resolution that yielded the target on the previous trial, as proposed by Robertson (1996). The level-specific effect suggests a bias to shift attention to one end or the other of the overall range of resolutions while maintaining some information about their relative proportions. Thus, if trial *N* contained a local target, there would be a bias to attend toward the higher resolutions during trial $N + 1$. In this way, level-specific priming could occur independent of changes in stimulus size. Such a mechanism, however, would be inefficient in Experiment 3, in which the range of resolutions defined by the stimulus components was equal on every trial. Here, a shift toward one of the extremes could result in attention being directed to a resolution that primarily contained irrelevant information with regard to the target. Under these conditions, it appears that attention remains centered on the particular resolution corresponding to that of the previous target.

Although our study focused on the role of target level—or relative target size—and of target resolution—or absolute target size—the results can be tentatively interpreted in terms of spatial frequency components as well (Hughes et al., 1990; LaGasse, 1993; Shulman et al., 1986; Shulman & Wilson, 1987). Inherent in the global–local distinction is the assumption of relative values. A global form is the whole that contains the local parts, whether the parts and wholes are quite large or rather small. In terms of spatial frequency, this means that local elements are defined by the relatively higher ranges of the spatial frequency spectrum, whereas information about global elements is carried at a lower range (at least within the spectral range of visual sensibility). Thus, the spectral differences between global and local elements may be described as differences in relative or absolute spatial frequency. The range of task-relevant information can, of course, vary depending on the actual sizes of the stimuli (Kinchla & Wolfe, 1979; Lamb & Robertson, 1990). This relational quality, which is characteristic of global–local processing, has been interpreted to indicate that these effects arise primarily from higher order attentional mechanisms (Lamb & Robertson, 1990). In the current study, target level and target resolution corresponded to relative and absolute target size and thus, although the mapping was not precise (Hughes, Nozawa, & Kitterle, 1996), to relative and absolute spatial frequency.

Ivry and Robertson (1998) have proposed that dual frequency filtering (DFF) is necessary to account for the conversion of absolute frequencies into relative frequencies, or relative spatial resolution. The first selects the absolute frequency range that is relevant for the task, and the second selects the relative frequencies within the range.

Such a model fits the current data well. The level-based priming effects observed in Experiments 1 and 2 could have resulted from the adjustment of a frequency-dependent attentional filter to a particular frequency range during the selection. It is important to note that a critical component of the model is that the selected frequency range is initially determined relative to the entire spectrum of frequencies available in a stimulus. This frequency range is then parsed into higher and lower values to produce a representation in terms of relative frequencies. The filter remains at this relative setting until the next processing episode, when a new stimulus is encountered. On the subsequent trial, if the target appears at the same level, the filter-setting confers an advantage to relative frequencies through reactivation of the DFF mechanisms. If relative and absolute values remain the same across stimuli, either one or both could account for the results.

This particular characterization of the present data accounts well for the fact that priming was purely level dependent in Experiments 1a and 1b, purely resolution dependent in Experiment 3, and involved both relative and absolute values in Experiment 2. In Experiments 1a and 1b, the size of the entire hierarchical letter pattern was manipulated so that target level could vary independently from target resolution. Because it is based on a bias that favors relative spatial frequency values scaled according to the available spectrum on a given trial, the model discussed above provides a straightforward mechanism for level-based facilitation occurring in the absence of target-resolution effects, as was found in the first experiment. In the last experiment, because a filler element equated the spatial extent and consequently the range of spatial frequencies present in each display, the attentional filter produced priming that appeared to be reliant on target resolution alone. In this case, relative spatial frequencies were synonymous with absolute spatial frequencies.

Finally, and most interestingly, this same model can account for the mixture of effects seen in Experiment 2. The addition of a frame added information to the stimulus displays at both the highest and lowest portions of the spatial frequency spectra. The high spatial frequencies corresponded to the edges that define the inside and the outside perimeter of the frame. The frame also added information at the lower range because of its peripheral location and overall size. There were variations in relative resolution within this frame, but the frame also acted to retain spectral information across a wide range. In essence, as in Experiment 3, the inclusion of the frame may act to reconfound relative and absolute spatial frequency. However, unlike the filler manipulation of Experiment 3, the presence of the frame was irrelevant for target identification. Because the frame is relatively easy to distinguish from the hierarchical letters themselves, it could have been eliminated early from consideration as a candidate target through the initial filter of the DFF model. Variation within this filtering stage would have the effect of maintaining more absolute frequencies on some occasions than on others, resulting in a mixture of relative and absolute level priming over trials.

Although the DFF model is consistent with the current data, the critical test for spatial frequency involvement in the priming effects that we have described necessitates a more direct manipulation of spatial frequency content than is allowed by merely manipulating target resolution. For future work, studies incorporating spectrally filtered stimuli will be used to address this question.

Whether this account is entirely correct or not, it is clear from the present work that both the absolute and relative attributes of a hierarchical stimulus contribute to level-specific priming. These findings necessitate mechanisms that respond to both and that use either or both in a subsequent target-level selection.

What might be the advantage of favoring a level-based mechanism? Such a mechanism would keep attention appropriately focused on relevant information as an object changes in overall size, as with movement or changes in viewing conditions. That is, because our perceptions of objects are rarely invariant over successive exposures, it seems reasonable that attentional mechanisms that decompose or otherwise prepare object representations for subsequent processing should be based on stimulus features that produce constancy in a changing visual world, such as level, or relative resolution. The absolute resolution of a target, however, is sensitive to variation in viewing condition and would therefore be unlikely to serve as an effective feature for parsing visual forms that vary in size across trials. It would be interesting to know if these two types of priming occur with other features, such as contrast, when there are both absolute and relative values.

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