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Attention switching between global and local elements: Distractor category and the level repetition effect

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When selecting information at global and local levels of hierarchical stimuli, there is a robust effect of level repetition in which performance is more efficient when a target is presented at the same level as the previous target. Moreover, the effect is symmetrical; it affects global and local processing equally. Evidence exists to suggest the effect may be automatic; however, we show here that the level repetition effect requires some amount of competition from the ignored level, and that the nature of the irrelevant information can determine whether the level-repetition effect is symmetrical (global and local responses are affected equally) or asymmetrical (global responses are more greatly affected than local responses). In Experiment 1, the level-repetition effect was eliminated when information at the distracting level was invariant across trials; effects of hemisphere bias and level repetition were observed only when suppression or filtering of distractor information was required. Experiment 2 demonstrated that simple featural variance is sufficient to produce the level repetition effect and that the symmetry of the level-repetition effect is sensitive to Garner-type interference that affects global processing to a greater extent than local processing. In Experiment 3, we showed that the absence of a level-repetition effect in the invariant distractor condition persists when the position of relevant stimuli is random within a block, a manipulation which should greatly reduce the contribution of controlled attention. We conclude that simple featural variance at the ignored level is critical to produce the advantage of level repetition, and that the size of the effect can be asymmetrical.

Our visual world is hierarchical in nature in the sense that almost any global object or scene can also be analysed in terms of its local parts. The brain appears

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to process local and global information differently, revealed by such well-studied phenomena as global precedence (faster responses to global information, May, Gutierrez, & Harsin, 1995; Navon, 1977, 1981), asymmetric interference patterns (global information interferes with local processing more than local interferes with global: Navon, 1977), and lateralized neural responses (right hemisphere bias for global and left hemisphere bias for local processing: Martin, 1979; Martinez et al., 1997; Palmer & Tzeng, 1990). The focus of this paper is the level-repetition effect, a phenomenon that engages distinct global/local mechanisms; however, in contrast to the many differences between global and local processing, level-repetition appears to affect global and local processing similarly.

These experiments were designed to test the hypothesis that the level repetition effect is sensitive to the nature of the information carried at the ignored or opposing level. More specifically, we tested hypotheses that filtering of irrelevant information at the opposing level is necessary to observe effects of level repetition and hemisphere biases (Experiment 1), that simple featural variance at the opposing level is sufficient to produce the filtering and the level repetition effect (Experiment 2), and that focused attention is not a factor in the absence of the level-repetition effect when no filtering is required (Experiment 3).

THE LEVEL-REPETITION EFFECT

The level-repetition effect is a robust phenomenon by which responses are completed more quickly if the target level (global or local) on trial N is the same as the target level on trial N–1 (Hubner, 1997, 2000; Lamb & Yund, 1996; Lamb, London, Pond, & Whitt, 1998; Lamb & Yund, 2000; Robertson, 1996; Ward, 1982). This phenomenon was first identified by Ward (1982) who called it the level readiness effect. Level-specific priming effects are long-lasting (at least 3 seconds), are not dependent on repetition of target shape, identity, or location, are not sensitive to changes in colour, polarity, or contrast between primes and probes, and are equal in magnitude for global vs local priming even when global and local response times are not equal (Robertson, 1996). The source of the advantage for level repetition is currently under debate, but its existence implies that shifting attention between global and local levels requires resources, regardless of the direction of the shift: global to local or local to global. The level-repetition advantage arises, in part, from the savings of not having to shift attention when the relevant level repeats. Thus, it is important to understand the mechanisms of level selection.

MECHANISMS OF LEVEL SELECTION

Global/local selection may be facilitated by altering the size of the attention window (Heinze, Hinrichs, Scholz, Burchert, & Mangun, 1998; Lamb & Robertson, 1988; Robertson, Egly, Lamb, & Kerth, 1993a; Stoffer, 1993), in which the ''attentional window'' refers to the attentional spotlight analogy (Broadbent, 1982; Posner, 1980) and the ability to change the spatial extent of the spotlight as described by the zoom lens analogy (Eriksen & St James, 1986). According to the regional selection hypothesis (Robertson et al., 1993a), selection of the object involves selection of the spatial region that the object occupies; global selection is facilitated by a larger spatial window than is local selection. In this view, the level-repetition effect might be explained as the difference in time required to resize the attentional window. If attention is sized for global or local on one trial, then a response to a target on the next trial will be faster if the target level is repeated because resizing is not necessary. If the target level switches then attention must switch as well and this involves resizing the attentional window. However, evidence that level-specific priming occurs even when the target changes location in the visual field argues against the idea that regional selection is entirely responsible for the advantage of level repetition (Robertson, 1996).

There is some debate over the role of spatial frequency in global/local selection processes (Lamb & Yund, 1996, 1993; Lamb, Yund, & Pond, 1999; Robertson, 1996, 1999). Global and local elements differ in the range of spatial frequencies which define them, and some evidence suggests that spatial frequency may play a role in the selection process (Ivry & Robertson, 1998; Robertson, 1996; Shulman & Wilson, 1987). However, Lamb and Yund (1996) argue that although spatial frequency is the basis for global dominance (faster overall responses that occur for global than local items; see also Hughes, Nozawa, & Kitterle, 1996), spatial frequency is not critical for the process by which global or local information is selected. When low spatial frequencies were reduced or eliminated, the response time advantage for global targets was reduced, but the level-repetition effect was not affected, responses were still faster when the target level repeated (see also Hubner, 2000). According to Lamb and Yund (1996), the level-repetition effect is due to the automatic activation of level-specific mechanisms that do not depend on spatial frequency.

In contrast, Robertson (1996, 1999) demonstrated a link between level-specific priming and spatial frequency with hierarchical stimuli constructed of contrast-balanced dots to remove lower spatial frequencies. This manipulation eliminated level-specific priming, even when observers expected the target to appear at the global or local level due to probability manipulations. Robertson (1996) proposed a model in which priming by level repetition acts at a stage at which global and local representations are categorical (and thus equal), and that faster responses are due to differential weighting of low and high spatial frequency channels; the weighting is affected by processing that occurred on the previous trial.

The persistence and symmetry of level-repetition effects may also be explained in terms of interference at the level of task-shifting, at a stage where global and local processing have equal status. Hubner (2000) compared level-shifting to task-shifting accounts (Allport, Styles, & Hsieh, 1994; Rogers & Monsell, 1995), such that identification of global and local items require different task sets. An association develops between the stimulus and response resulting in an automatic tendency to respond to that stimulus level on the next trial even though the task has shifted so that a response to the other level is now required. This automatic tendency produces a task-set inertia which affects global and local processing equally and contributes to the symmetric level-repetition effect.

Thus, priming of level across trials may occur due to differential weighting of low or high spatial frequency channels based on previous processing along those channels (Robertson, 1996; Robertson et al., 1993a), to the automatic activation of level-specific mechanisms, in which case processing is more efficient when level repeats because the appropriate neural mechanisms are already active (Lamb & Yund, 1996), or to task-set inertia, in which there is a tendency to respond to the stimulus-response mapping evoked by the global or local stimulus that was processed on the previous trial (Hubner, 2000). These different hypotheses are similar in the sense that they predict the symmetry of the level-repetition effect, that regardless of whether one thinks of level-specific priming in terms of the advantage of level repetition or the disadvantage of level switching, the effect size is the same for global and local processing.

HEMISPHERE BIASES FOR GLOBAL/LOCAL PROCESSING

Although many studies have demonstrated the persistence of level-repetition priming, it is still not clear what factors contribute to activation of level-specific mechanisms and the level-repetition effect. It is clear from many studies that there are separate neural mechanisms that appear to be biased for processing global or local information. Observations from clinical populations provide compelling evidence for lateralization of global/local processing in which the left hemisphere (LH) is specialized for local processing and the right hemisphere (RH) is specialized for global processing (Delis, Robertson, & Efron, 1986; Robertson & Lamb, 1991; Robertson, Lamb, & Knight, 1988). For example, when asked to reproduce a Navon figure from memory, patients with damage to the temporal-parietal junction (TPJ) in the LH tended to produce only the global outline of the figure, whereas RH-TPJ damaged patients produced the local elements but failed to organize them into the global pattern (Delis et al., 1986). Split-brain patients also show the same pattern of lateralization, demonstrating superior performance when processing global stimuli presented to the left visual field (LVF-RH) and local stimuli presented to the right visual field (RVF-LH) (Delis, Kramer, & Kiefner, 1988). Brain-imaging studies of normal subjects also lend support for this pattern of global/local hemispheric biases (Evans, Shedden, Hevenor, & Hahn, 2000; Fink et al., 1996;

Heinze et al., 1998; Heinze & Munte, 1993). Based on the neuropsychological studies, the TPJ may be the neural locus for the hemisphere bias (Delis et al., 1986; Rafal & Robertson, 1995). Although the precise mechanisms are unknown, it is likely that the distinction between the biased LH and RH pathways is critical for understanding level-specific priming.

It is interesting that level-specific priming effects are not observed in patients with damage to the inferior parietal region, even though these patients do not have trouble selecting and responding to the correct stimulus, suggesting that while the right and left TPJ may be instrumental during global/local processing, the inferior patietal lobules may be critical for level-specific priming (Rafal & Robertson, 1995). This suggests that this area may be involved in a process that slows responses when attention must switch levels, possibly due to filtering of information at the irrelevant level.

IMPORTANCE OF PERCEPTUAL VARIABILITY AT THE OPPOSING LEVEL

Previous event-related potential (ERP) work led to the hypothesis that the properties of the distractors at the opposing level are important (Evans et al., 2000). In those experiments, the perceptual variability of the distractors at the irrelevant level (global if attending locally, and local if attending globally) determined the stage at which hemisphere biases for local (LH) vs global (RH) processing were observed. The distractor-variability effect for the ERP results is as follows. Distractors are variable when the items at the ignored level are different on every trial; distractors are invariable when the items at the ignored level are the same on every trial. When distracting information was variable, it appeared that both hemispheres were engaged in processing at early perceptual stages, and global/local differences in activity between the hemispheres did not appear until later stages (250 ms). When distracting information was invariable, differences in processing (global-RH and local-LH) between the hemispheres was evident at early stages (95 ms) (Evans et a., 2000).

Our hypothesis is that both global and local level-specific mechanisms are active when the information at the ignored level is variable and that this activity is automatic, engaging both hemispheres at early processing stages. More simply, there is some automaticity in the visual system to process new things. Thus, when distractors are variable there is some effort required to filter that information. However, when the items at the ignored level are invariable only the attended-level mechanism (global-RH or local-LH) is activated. The distractor (ignored) level mechanism is not engaged because there is no new perceptual information presented to the ignored level. Thus, there is greater level-specific activity for the attended hierarchical level, and differential activity between the hemispheres is observed at early perceptual stages. Importantly, less effort is required to filter the invariable distractor information.

Although Evans et al. (2000) did not require attention shifts between levels, they clearly showed that the variability of the information at the distractor (ignored) level affected the engagement of global vs local hemispheric processes. Based on the results of that study we hypothesized that the nature of the information presented at the distracting level might be an important factor for whether or not we observe the advantage of level repetition or, in other words, the cost of level switching. There is some cost to switching levels even when the onset of the stimulus is under observer control (Hubner, 2000), suggesting that thee is some perceptual stimulus-related processing related to the shift that can not be totally prepared for or that cannot occur until the stimulus appears and processing begins. We hypothesize that the duration of this delay is affected by interference from irrelevant information at the distractor level. In this view, the level-repetition advantage occurs not only because level-specific mechanisms are primed but also because filtering of distractor information at the ignored level is easier if that filtering occurred at the same level on the previous trial, and much harder if that level was the attended level on the previous trial. If there is relatively little featural variability at the ignored level, then filtering is not necessary, reducing the advantage of level repetition.

The following three experiments investigate the relation between the distractor-variability effect and the level-repetition effect. We make the following predictions: (1) The level-repetition effect will differ between the conditions in which variable and invariable distractror information is present at the opposing level and (2) the invariable distractor condition will show a much smaller level repetition advantage than the variable distractor condition. Moreover, (3) responses will be faster over all when distractors are invariable vs variable, and (4) there will be a hemisphere-bias effect for variable but not for invariable distractors.

EXPERIMENT 1

The *digit-sequence task* was used in all three experiments, the same task used in Evans et al. (2000; see also Shedden & Reid, 2001). This required continuous monitoring of digits presented in sequence and execution of a response when an out-of-sequence digit was detected. For example, in the digit sequence ''123956789173456789'', the first ''9'' and the second ''7'' are targets. On each trial, the task-relevant digits were presented at the global or local level and the identity of the distractor at the other level depended on the distractor condition (different for each experiment; discussed in the Methods sections). We used this task because of its variable mapping between stimulus and response (Shedden & Reid, 2001). The digit-sequence task was more demanding than a simple target detection task because the set of possible targets changed on each trial. There was a variable mapping between stimulus and response such that a digit could be a distractor on one trial and a target on the next trial. For example, in the digit sequence above, the first ''9'' requires a response but the subsequent two occurrences of ''9'' require withholding the response. Thus, no consistent mapping between stimulus and response is made for any of the stimuli, reducing the possibility that interference effects will be due to automatic processes at the response stage (Schneider & Shiffrin, 1977).

The *distractor-variability effect* was manipulated between groups. The distractors were either digits or neutral boxes, providing two very different levels of difficulty for selection. The digit distractors at the ignored positions changed on every trial, and were drawn from the same set of task-relevant digits, therefore selection of the relevant digit and filtering of the irrelevant digits was difficult. The box distractors were neutral and invariant from trial to trial. Relatively little filtering of ignored information was necessary for box distractors. We predicted that performance would be superior for box distractors.

The *level-repetition effect* was manipulated within groups. In each block of trials, attention was either fixed at global or local (level repetition) or alternated between global and local elements. If the level-repetition effect is the result of an automatic process which primes the level-specific mechanisms then level repetition should have an effect regardless of the category of the distractors. If, however, the level-repetition effect requires an additional process that involves suppression or filtering of ignored information then the effect may be observed only when the distractors provide interference. Importantly, the box distractor condition isolates the priming level-specific mechanisms from the cost of filtering because there is no (or very little) filtering needed. We predicted that we would observe an effect of level repetition but that it would interact with distractor-variability so that the cost of switching levels would occur for digit distractors only.

The *hemisphere-bias effect* (manipulated within groups) was predicted to show a global-RH and local-LH bias because level-specific mechanisms are hypothesized to be lateralized in the brain. Experiment 1 examined attention switching between hierarchical figures presented in the left (LVF) and right (RVF) visual hemifields. Of particular interest for observing the hemisphere bias effect was the ''double-switching'' condition, in which attention alternated between both levels and visual hemifields. In that case, the blocks can be described in terms of the RH and LH bias for global vs local information processing (see Column D of Figure 1 for an example of the stimuli in a double-switching block). There were two possible ways to double switch. In one case, attention alternated between the global level in the LVF(RH) and the local level in the RVF(LH). This was the positively biased condition in which the global/local information was delivered to the preferred hemispheres acccording to the global-RH and local-LH biases. In the other kind of double switching, attention alternated between the local level in the LVF(RH) and the global level in the RVF(LH). We called this the negatively biased condition because global/local information was delivered to the hemispheres opposite to the preferred hemi-

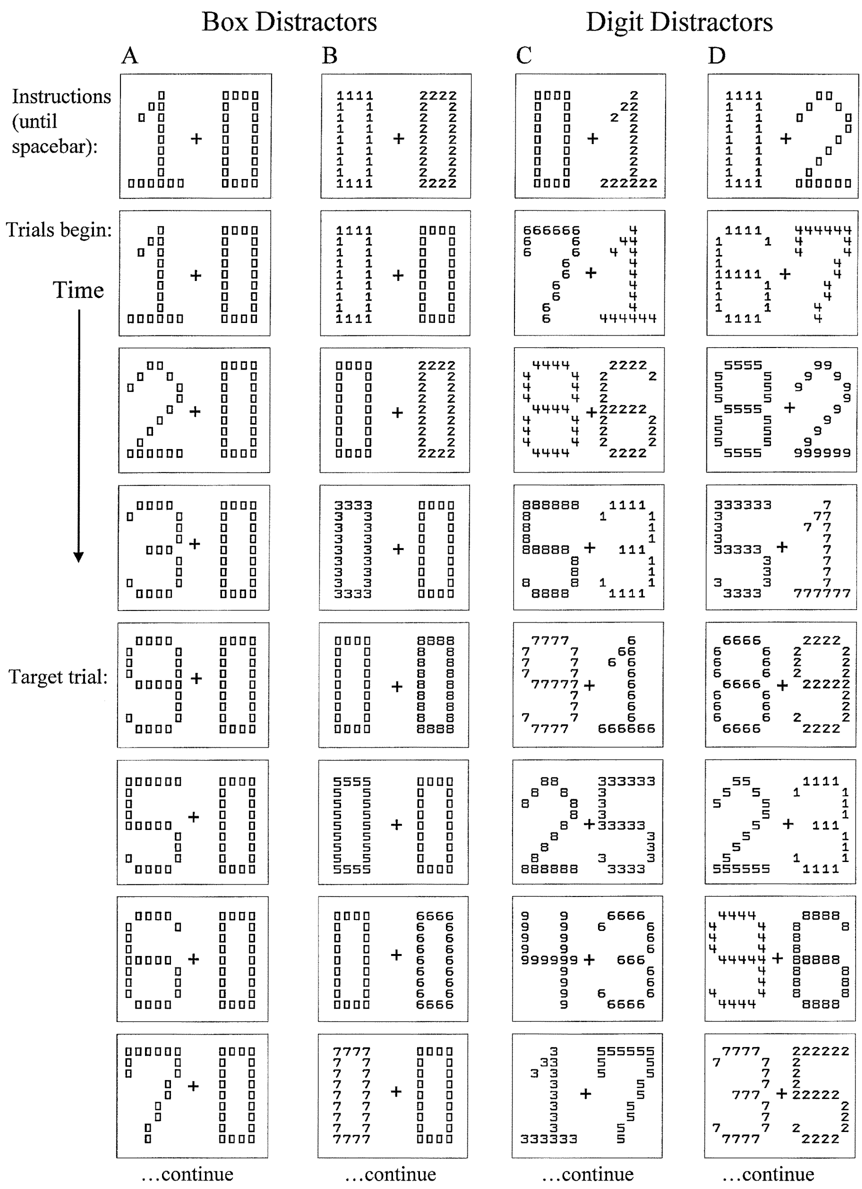

Figure 1. The four columns are examples of the first 7 (of 27) trials of 4 (of 16) different block types. At the top of each column is shown the block instructions which indicate the level (global/local) and visual field (LVF/RVF) to be attended on each trial (see Figure 2 for the full set of 16 block instructions). The instructions consist of LVF and RVF hierarchical figures which contain a ‘‘1’’ and (in the case of an attention switching block) a ‘‘2’’. On fixed-attention trials, attention is

figure caption continued opposite

spheres. In both cases, there should be a cost for switching levels, but this should interact with hemisphere bias. We predicted that processing would be most efficient in the positively biased condition and less efficient in the negatively biased condition. Moreover, there should be an additional interaction with distractor variability, such that hemisphere-bias (and level-repetition) effects occur in the digit-distractor condition only, and not in the box-distractor condition.

Method

Participants

Participants were 42 undergraduate students at McMaster University, participating for class credit. All participants were right handed as determined by a handedness questionnaire which consisted of a subset of questions drawn from the Edinburgh Inventory for handedness (Oldfield, 1971). All participants reported having normal or corrected to normal vision. All participants gave informed and written consent to participate. The 42 observers were distributed evenly across two distractor conditions (described in detail below).

Stimuli

The global and local patterns were designed separately, and combined to create the hierarchical stimuli by replacing each pixel in the global pattern with a local pattern.

Digits with digit distractors. One set of hierarchical stimuli consisted of global digits (1 through 9) constructed of local digits (1 through 9), producing 81 compound figures (see examples C and D in Figure 1). In all cases, the distractor digits were out-of-sequence with respect to the attended digit series.

Digits with box distractors. The box distractors were simple rectangles (Columns A and B in Figure 1). This produced an additional 19 compound figures: 9 digits made of boxes, boxes made of 9 digits, and boxes made of boxes.

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directed to the position of the ‘‘1’’ for all trials. On switching-attention trials, attention is directed to the ‘‘1’’ on odd numbered trials and to the position of the ‘‘2’’ on even numbered trials. This display remains on the screen until the spacebar is pressed to start the block of trials. At the attended level and visual field, digits are then presented in increasing sequence except for target trials to which a response is required. In each column, the fourth trial is an example of a target trial. Columns A and B illustrate trials from the box-distractor condition, and Columns C and D illustrate trials from the digit-distractor condition. Column A: Global LVF attention, no attention switching. Column B: Attention fixed at local level while switching between LVF and RVF. Column C: Attention fixed at the RVF while switching between global and local levels. Column D: Attention switching between global and local levels while also switching between LVF and RVF (double switching). Note that these columns represent only 4 of the 16 block types within each distractor group. Refer to Figure 2 for the full set of 16 instruction displays.

On each trial, two hierarchical stimuli were presented simultaneously to the left and right (LVF/RVF) of a central fixation cross. The global digits subtended $4.29 \times 5.71^\circ$ of visual angle (width × height), and the local digits subtended $0.38 \times 0.57^\circ$. The global digits were centered vertically and positioned 2.5° from the centre of the fixation cross to the centre of the global digit. The retinal size and position of the hierarchical stimuli were held constant by providing a chin rest and training participants to remain fixated on the central fixation cross.

Design

There were two types of distractors (digits and boxes), two levels (global and local), two attention states for level (fixed and switching), two hemifields (LVF and RVF), and two attention states for hemifield (fixed and switching). The distractor variable was a between-subject manipulation; all the other variables were within-subject manipulations. All conditions were crossed and presented in blocked trials. On all block types when attention was switching (alternating between levels and/or hemifields), the starting position was balanced. This produced a total of 16 types (see Figure 2). Of the 16 block types, 8 consisted of level-repetition trials in which attention was fixed at the global or local level, and was either fixed at or alternating between the LVF and RVF. The remaining eight block types consisted of level-switching trials in which attention alternated between global and local, and was either fixed or alternating between the LVF and RVF.

Procedure

Observers were seated in front of a computer monitor and made their responses on a computer keyboard. They were instructed to respond as quickly as possible without sacrificing accuracy. At the beginning of the session, the experimenter demonstrated the task, and observers were closely monitored during practice blocks to ensure they understood the directions and were performing the task correctly. The importance of keeping fixated was emphasized (no formal eye movement data were collected) and participants were reminded of this importance periodically during the practice blocks. There were 16 practice blocks followed by 32 blocks of 27 trials. The order of block type was random for each observer. At the beginning of each block, a display appeared to indicate the pattern of fixed or alternating attention (the full set of instruction displays are illustrated in Figure 2). The participant fixated the central cross and pressed the spacebar to start the trials. The sequence of trials began after a 1 s delay.

On each trial, at the attended level (global or local) and position in the visual field (LVF or RVF), a digit was presented. The digits increased in numerical sequence 1 through 9, the sequence repeating three times. For observers in the digit-distractor condition, the items at the unattended positions were other digits

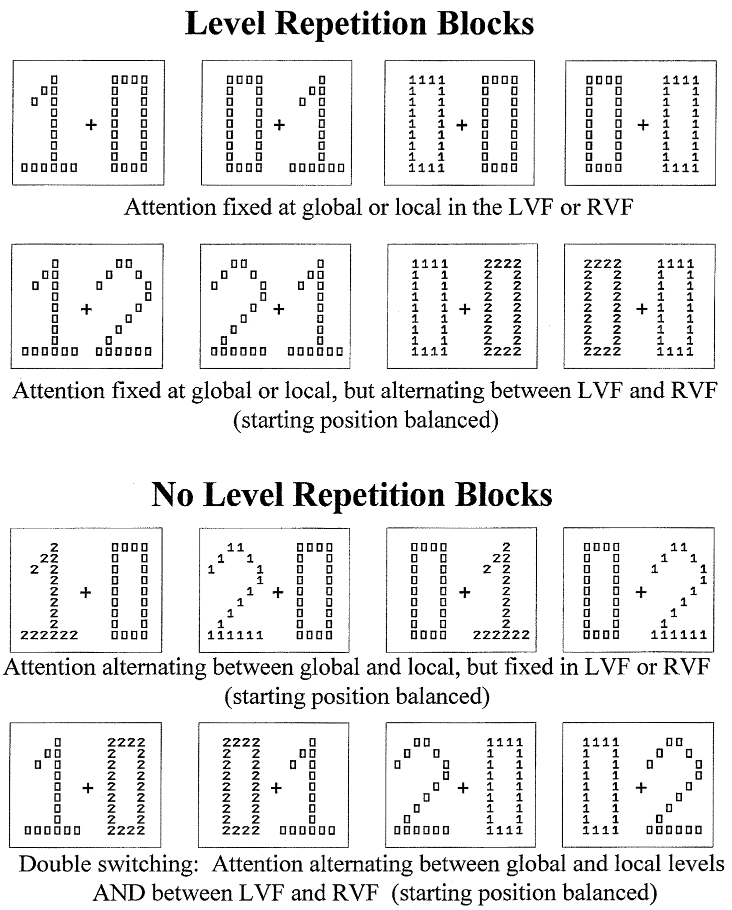

Figure 2. Block instructions were presented prior to each block to instruct the participant where to attend during the course of that block. There were 16 different block types. The top two rows illustrate the level-repetition blocks. The top row contains block instructions for fixed attention at one hemifield (LVF or RVF) and level (global or local); attention was directed to the location of the ''1'' for the entire block. The second row contains block instructions for fixed attention to level, but alternating attention between the hemifields. The position of the ''1'' indicated the attended position on odd-numbered trials and the position of the ''2'' indicated the attended position on even-numbered trials. The bottom two rows contain block instructions where no level-repetition occurs: The third row shows instructions that indicated switching hemifields (but not levels); the fourth row shows instructions that indicated switching between both hemifields *and* levels (double switching). Note that for the attention alternating blocks, the starting position was balanced.

(Figure 1, Columns C and D); for observers in the box-distractor condition, the items at the unattended positions were boxes (Figure 1, Columns A and B). Stimulus duration was 100 ms and stimulus onset asynchrony (SOA) was 900 ms. The fixation cross remained on the screen during the 800 ms interstimulus interval (ISI). Participants responded to occasional targets with a single keypress. A target was an out-of-sequence digit at the attended level and position. The probability of a target on each trial was approximately .25, resulting in approximately six to seven targets per block. Constraints were implemented such that two simultaneous or successive digits were never the same (including attended and unattended digits at any position or level), there were never targets presented in the first two or last two trials, and there were never two consecutive targets. The columns in Figure 1 show possible sequences of global/local figures for the first seven trials in a block (only 4 of the 16 possible block types are illustrated). The fourth trial in each example represents a target. Feedback was provided at the end of each block and consisted of number of hits, misses, and false alarms, as well as the average RT for hits. Participants were given as much time as they wanted to rest between blocks during which time the upcoming block instructions were displayed. Each block was 24.3 s in duration.

Results and discussion

The manipulations resulted in a five-factor $2 \times 2 \times 2 \times 2 \times 2$ design [Between-Subject factor] Distractor Category [digits/boxes] $\times$ [Within-Subject factors] Level [global/local] $\times$ Switching Levels [fixed/switching] $\times$ Hemifield [LVF/RVF] $\times$ Switching Hemifields [fixed/switching]. A five-factor repeated measures ANOVA was performed for both response time and accuracy measures. Slower response times were associated with poorer accuracy, confirming that participants were not trading speed for accuracy. The means and standard errors of the means for accuracy (A′) are displayed in Table 1, and for response times (RT) in Table 2, and in Figures 3 and 4.

Because responses were required only for targets, only hits, misses, and false alarms (and not correct rejections) were available for analysis. Accuracy was analysed using the nonparametric A′ measure, which estimates the equivalent proportion correct as if the paradigm had required both positive and negative responses and can be thought of as the area under the receiver operating characteristic (Green & Swets, 1966). A′ is calculated by first determining a hit rate (h = hits/[hits + misses]) and a false alarm rate (f = false alarms/[false alarms + correct rejections]). Correct rejections are estimated from those nontarget trials for which there was no response. The hit rate and the false alarm rate are then used to calculate A′: $A' = 0.5 + ([h-f] + [h-f]^2)/(4h[1-f])$.

Level-repetition effect. There were significant main effects of level and of switching levels. Responses were faster to global targets than to local targets,

TABLE 1

Experiment 1: Accuracy expressed as A′ (see text for details). Mean A′ and standard error of the mean for each group including Distractor Category (digits/boxes) × Hemifield (LVF/RVF) × Level (global/local) × Switching Hemifields (fixed/switch) × Switching Levels (fixed/switch)

	Fixed hemifield				*Switch hemifield*			
	Fixed level		*Switch level*		*Fixed level*		*Switch level*	
	M	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Digits								
LVF								
Global	.983	.004	.913	.014	.982	.007	.922	.014
Local	.977	.005	.916	.017	.969	.009	.896	.016
RVF								
Global	.979	.004	.912	.016	.970	.007	.867	.033
Local	.973	.004	.916	.017	.964	.012	.914	.017
Boxes								
LVF								
Global	.988	.005	.987	.004	.995	.002	.992	.003
Local	.977	.001	.992	.003	.987	.004	.990	.005
RVF								
Global	.990	.003	.983	.005	.997	.001	.989	.005
Local	.991	.003	.989	.004	.991	.003	.986	.005

TABLE 2

Experiment 1: Mean RT (ms) and standard error of the mean for each group including Distractor Category (digits/boxes) × Hemifield (LVF/RVF) × Level (global/local) × Switching Hemifields (fixed/switch) × Switching Levels (fixed/switch)

	Fixed hemifield				*Switch hemifield*			
	Fixed level		*Switch level*		*Fixed level*		*Switch level*	
	M	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Digits								
LVF								
Global	571	14	612	19	577	17	634	24
Local	601	16	644	25	592	16	661	27
RVF								
Global	576	18	643	23	584	17	604	16
Local	591	14	635	24	598	18	633	29
Boxes								
LVF								
Global	508	9	526	9	515	11	513	11
Local	517	11	532	12	516	9	522	9
RVF								
Global	509	11	518	15	515	11	523	13
Local	505	10	521	13	507	13	514	13

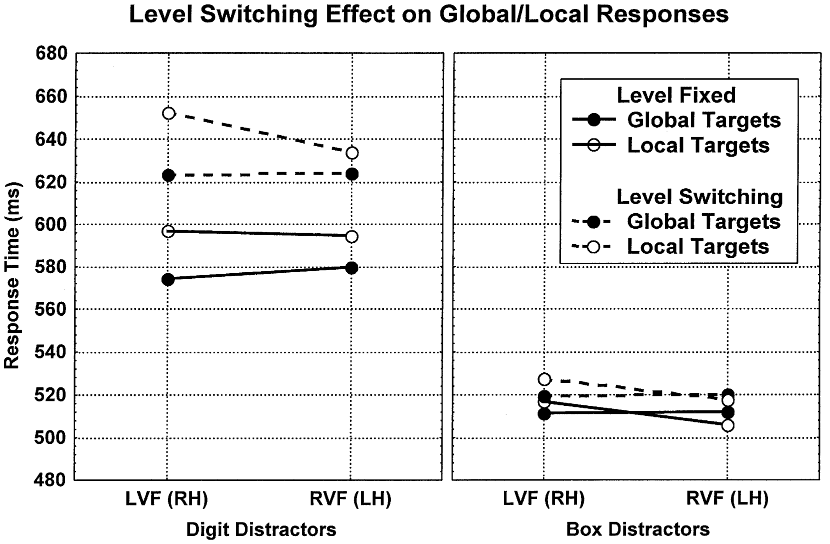

FIgure 3. Response time means contrasting the difference between digit and box distractors and showing the effect of level switching (fixed at a level or switching between levels) on the speed of global and local target detection.

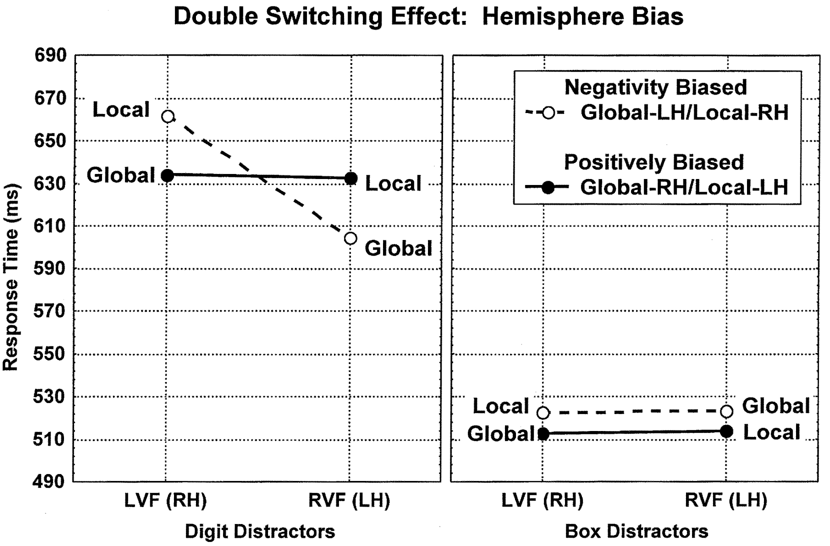

Figure 4. Response time means contrasting the difference between digit and box distractors and illustrating the hemifield bias for global and local attention when participants were double switching. On positively biased double-switching blocks, attention shifted between levels and hemifields for which the hemispheres were positively biased for the information presented to the contralateral visual hemifield (between global-RH and local-LH). On negatively biased double-switching blocks, attention shifted between levels and hemifields for which the hemispheres were negatively biased for contralateral information (between global-LH and local-RH).

which is a typical observation with hierarchical stimuli, level RT: $F(1, 40) = 6.2$, $MSE = 2841$, $p < .02$. Responses were also faster and more accurate for level repetition trials, Switching Levels A′: $F(1, 40) = 31.9$, $MSE = 0.007$, $p < .00001$; RT: $F(1, 40) = 26.1$, $MSE = 5157$, $p < .0001$, replicating the level-repetition effect. Then the more interesting question is what occurred when taking into account distractor category.

Distractor-variability effect and level repetition. Distractor category had a significant main effect on RT and accuracy, showing that responses were faster and more accurate overall when distractors were boxes than when they were digits, Distractor Category A′: $F(1, 40) = 28.1$, $MSE = 0.014$, $p < .00001$; RT: $F(1, 40) = 24.3$, $MSE = 60553$, $p < .0001$.

Moreover, distractor category interacted with the factors level and switching levels (Figure 3). Only for digit distractors were responses faster and more accurate when attention was fixed at either the global or the local level than when switching between them; in the box-distractor condition, RT and accuracy did not differ between fixed and switching attention conditions, Switching Levels × Distractor Category on A′: $F(1, 40) = 26.1$, $MSE = 0.007$, $p < .0001$; RT: $F(1, 40) = 11.4$, $MSE = 5157$, $p < .01$. A similar pattern occurred for the level effect on RT, the advantage for global responses occurred only in the digit-distractor condition; in the box-distractor condition there was no difference between local and global responses, Level × Distractor Category on RT: $F(1, 40) = 4.8$, $MSE = 2841$, $p < .05$. These results support the hypothesis that the distractor variability affects the advantage for level repetition. The cost for switching levels is minimal or absent when distractors are invariable boxes.

Hemisphere-bias effect and double switching. Interactions with the hemifield and switching hemifield factors supported global-RH and local-LH processing biases. There was better accuracy for global targets and slower responses to local targets presented to the LVF(RH), consistent with a RH bias for global processing, Switching Hemifields × Hemifield × Level A′: $F(1, 40) = 5.1$, $MSE = 0.001$, $p < .05$; Hemifield × Level RT: $F(1, 40) = 9.9$, $MSE = 637$, $p < .01$.

A four-way interaction involving Switching Hemifields × Switching Levels × Hemifield × Distractor Category, RT: $F(1, 40) = 3.98$, $MSE = 2294$, $p = .053$, was marginally significant; the pattern of response times suggests that the hemifield differences were restricted to the digit-distractor condition and were most enhanced in the double-switching condition. More specifically, the hemisphere differences were largest when switching between levels in the digit-distractor condition ($p < .05$); the box-distractor condition showed no difference (Table 3, Figure 4). The four-way interaction is examined more effectively by looking specifically at the double-switching results, as was planned. As discussed earlier, there were two kinds of double-switching trials. In one case,

TABLE 3
Experiment 1: Accuracy analysis using A′ and response time for the double-switching condition (switching levels and switching hemifields), sorted in terms of whether attention was directed to global and local information in the positively (global-RH/local-LH) or negatively (global-LH/local-RH) biased hemisphere. Mean and standard error of the mean for each group including Distractor Category (digits/boxes) × Bias (negative/positive) × Hemifield (LVF/RVF)

	Negatively biased hemisphere				*Positively biased hemisphere*			
	Local/LVF (RH)		*Global/RVF (LH)*		*Global/LVF (RH)*		*Local/RVF (LH)*	
	M	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
A′								
Digits	0.867	0.033	0.896	0.016	0.922	0.014	0.914	0.017
Boxes	0.989	0.005	0.990	0.005	0.992	0.003	0.986	0.005
RT (ms)								
Digits	661	27	604	16	634	24	633	29
Boxes	522	9	523	13	513	11	514	13

attention switched from global in the LVF(RH) to local in the RVF(LH). In that case, both global and local elements were first processed in the hemisphere that was biased for that level (the positively biased hemispheres). In the other case, attention switched from global in the RVF(LH) to local in the LVF(RH), so that both global and local elements were first processed in the hemisphere that was biased for the other level (the negatively biased hemispheres).

The double-switching data were coded for distractor category (digits/boxes), attended hemifield (LVF[RH]/RVF[LH]), and for hemisphere bias (negative/positive), and planned comparisons were performed separately for digit- and box-distractor conditions. The tests did not reach significance for RT or A′ in the box-distractor condition ($F < 1$). In the digit-distractor condition, when switching between local and global in the positively biased hemispheres, response times were equal and accuracy did not differ for the global-LVF(RH) and local-RVF(LH) targets ($F < 1$). When switching between local and global in the negatively biased hemispheres, responses to global-RVF(LH) targets were speeded and responses to local-LVF(RH) targets were slowed and tended toward lower accuracy, RT: $F(1, 40) = 11.0$, $MSE = 3105$, $p < .01$; A′: $F(1, 40) = 3.62$, $MSE = 0.009$, $p = .06$.[1]

[1] If one analyses the double-switching trials by ignoring the blocking manipulation and comparing global/local processing in the LVF vs RVF, then the analgous statistics show a hemifield difference (RVF response time advantage) for global targets when distractors are digits, $F(1, 40) = 4.16$, $MSE = 2920$, $p < .05$, which does not reach significance for local targets, $F(1, 40) = 2.99$, $MSE = 2259$, $p = .09$. There is no hemifield effect for either global or local targets when distractors are boxes ($F < 1$).

The interpretation of this pattern of results draws from the following hypotheses. Substantial evidence exists that under the right circumstances global processing is dominant over local processing (Blanca, 1992; Boer & Keuss, 1982; Paquet, 1999; Shedden & Reid, 2001) and that there is a bias for global and local processing in the RH and LH, respectively (Delis et al., 1986; Evans et al., 2000; Fink et al., 1996; Heinze et al., 1998; Heinze & Munte, 1993; Kimchi & Merhav, 1991; Robertson, Lamb, & Zaidel, 1993b; Sergent, 1982). Further, the RH is specialized for spatial orienting of attention (Behrmann & Tipper, 1994; Caramazza & Hillis, 1990; Mesulam, 1983) and there is other evidence that the hemisphere biases for global and local processing may not be symmetric. For example, a global/local fMRI experiment showed greater activity in the right occipitotemporal regions for global over local processing, but equal activity in LH regions for global and local processing (Martinez et al., 1997). In our task, when alternating attention between global and local items presented to the positively biased hemispheres, global dominance in the RH did not compete with local processing in the LH, and processing may have occurred relatively independently, producing comparable response efficiency. In contrast, when alternating between the negatively biased hemispheres, the dominance of global processing in the RH produced a disadvantage for local processing. Both LH and RH may have engaged in global processing, increasing the competition for local processing and making the switch from global to local difficult.

Just as we did not observe a level-repetition effect for box distractors, neither did we observe a hemisphere-bias effect when distractors were boxes. The most likely explanantion is that digit and box distractors differed in the filtering required to ignore them and that response time increased when filtering demands were greater. The distractor digits were drawn from the same stimulus set as the task digits, whereas the boxes were never associated with a response. Moreover, the box distractors were less likely to attract attention because they were invariant across trials, whereas each trial presented a new set of digit distractors. These differences may have contributed to more difficult selection of the items at the target level in the digit-distractor condition.

The current results support the hypothesis that the level-repetition effect has some relation to level-specific processes in the LH and RH because both level-repetition and hemisphere-bias effects are affected by the same distractor category manipulation. Moreover, there is support for the idea that engagement of level-specific mechanisms occurs involuntarily when a stimulus is identified at the global or local level. Data from previous ERP studies clearly show that level-specific mechanisms were engaged in both the digit and box distractor conditions (Evans et al., 2000). However, the current results show that engagement of level-specific mechanisms does not always lead to a priming effect. The box-distractor condition isolated the activation of level-specific mechanisms from the cost of filtering because there was relatively little filtering required. The conclusion is that activation of a level-specific mechanism is not sufficient to produce priming unless there is also processing competition from the other level.

The digit and box distractors represented extreme differences in level of interference. Is it the case that any variability at the ignored level is sufficient to produce the level-repetition advantage, regardless of the content of the information carried there? Experiment 2 was designed to test intermediate levels of interference to ask what level of filtering is necessary to produce the level-repetition effect.

EXPERIMENT 2

Experiment 2 focused on the interaction between the level-repetition effect and the category of the distractors; on each trial a single compound figure was presented in the centre of the screen. There were four distractor conditions: Digit, letter, symbol, and box distractors. These distractor sets provided varying degrees of interference. The digit and box distractors were the same as used in Experiment 1 and we expected to replicate those results. We expected that the letter and symbol distractors would fall somewhere between digits and boxes in terms of level of filtering required.

Digit distractors provided the most interfering information as they were the same category and content as the targets. Boxes carried the least interfering information as they were invariable and not associated with a response. Letter and symbol distractors were designed to be feature-similar to the digits, and like the digit distractors they were variable from trial to trial. Like the box distractors they were not associated with a response, yet they provided very different levels of interference. Letters are a well-learned category, as are digits. It has been demonstrated that visual information is categorized as a letter or digit before it is identified as a particular letter or digit (Dixon & Shedden, 1987). Thus, it might be possible to ignore the letter distractors with relative ease, discounting them at an early stage of processing. The symbol distractors were not part of a well-learned category and they were natural in the same sense that the box distractors were natural. However, the symbol distractors varied in featural configuration from trial to trial. It may be that simple variance of features provides enough interference from the distractor level to produce the level-repetition advantage.

Method

Participants

Participants were 72 undergraduate students at McMaster University, participating for class credit. All participants were right handed as determined by a handedness questionnaire which consisted of a subset of questions drawn from the Edinburgh Inventory for handedness (Oldfield, 1971). All participants had normal or corrected to normal vision. The 72 observers were distributed across the four distractor conditions.

Stimuli

The stimuli for the digit- and box-distractor conditions were the same as used in Experiment 1. For each of the nine global and nine local digits, a letter was chosen and designed to equate as closely as possible the general shape and numbers of features that made up that particular digit. Nine letters were so designed and combined with digits to create 162 compound figures in this group (nine global digits made of nine local letters and nine global letters made of nine local digits). As was done with the letter distractors, the symbol distractors were designed to match the digits with respect to features. Nine symbols combined with digits created another 162 compound figures. A subset of the 423 compound figures is illustrated in Figure 5.

Stimuli were presented in the centre of the monitor screen; the retinal size and position of the hierarchical stimuli were held constant by providing a chin rest. The global elements subtended $4.29 \times 5.71^{\circ}$ (width $\times$ height), and the local elements subtended $0.38 \times 0.57^{\circ}$ of visual angle.

Design and procedure

There were four types of distractors (digits, letters, symbols, and boxes), two levels (global and local), and two attention states for level (fixed and switching). The distractor variable was a between-subject manipulation; all the other variables were within-subject manipulations. All conditions were crossed and presented in blocked trials. On all block types during which attention was switching (alternating between levels), the starting position was balanced. This produced a total of four types of blocks. Of the four block types, two consisted of level repetition trials in which attention was fixed at the global or local level (examples in Columns A and B, Figure 5) and two consisted of level switching trials in which attention alternated between global and local elements (examples in Columns C and D, Figure 5). There were 48 blocks of 27 trials each, including 8 blocks at the beginning of the session that were considered practice. The columns in Figure 5 show examples of the hierarchical figures and the block instructions (the display at the top of each column) followed by possible sequences of global/local figures for the first seven trials in a block. The fourth trial in each example represents a target. All other aspects of the procedure were identical to Experiment 1.

Results and discussion

The manipulations resulted in a three-factor $4 \times 2 \times 2$ design (Between-Subject factor) Distractor Category (digits/letters/symbols/boxes) $\times$ (Within-Subject

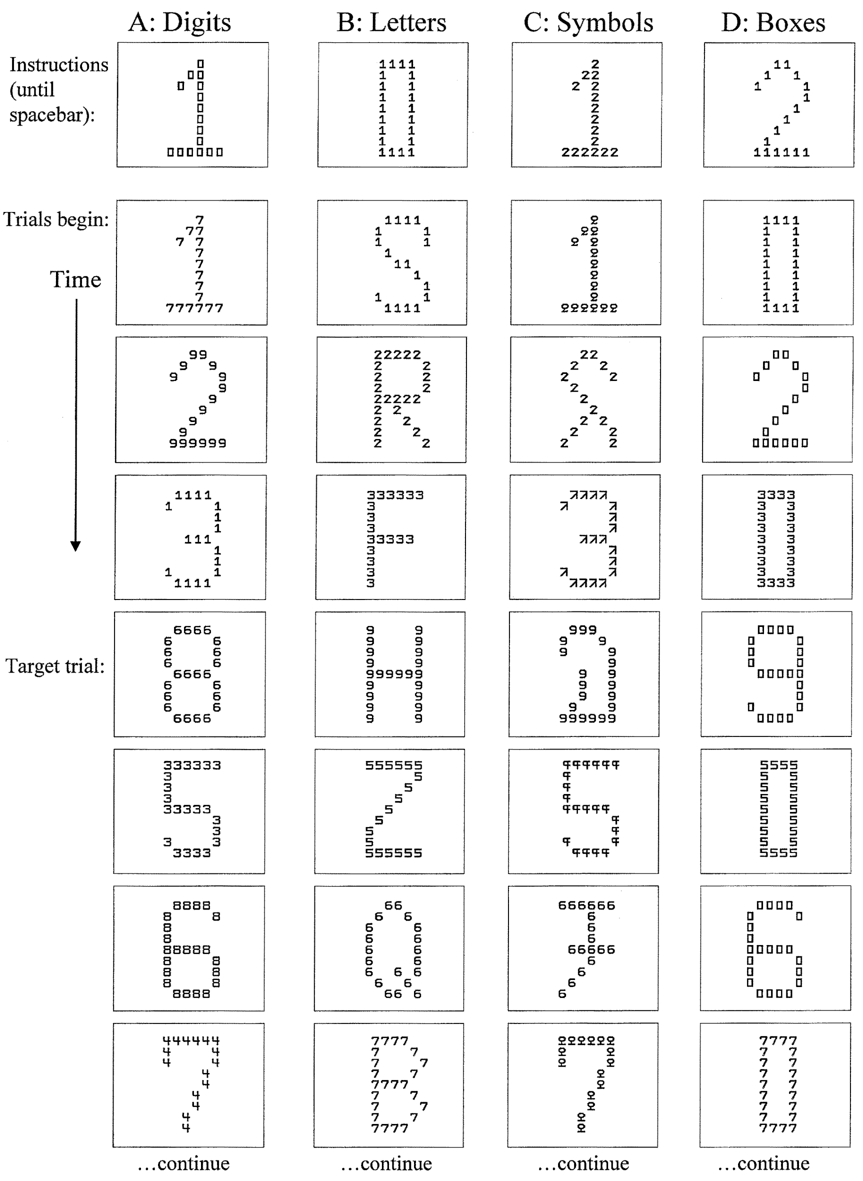

Figure 5. The four columns are examples of the first 7 (of 27) trials of four different attention conditions. Each column illustrates one attention condition and one distractor condition, but it should be noted that all of the attention conditions were tested for all four distractor conditions. At the top of each column is shown the display containing the block instructions which indicated the level (global/ local) to be attended. Attention was directed to the position of the ''1'' on all trials, or (in the case of

figure caption continued opposite

factors) Level (global/local) × Switching Levels (fixed/switching). Repeated measures ANOVA was used to analyse RT as well as accuracy calculated as A′. Post hoc comparisons of means used the Newman-Keuls test. Figure 6 provides illustrative details of the results of the RT analysis and Table 4 provides the means for RT and A′.

A further analysis was performed to test the size of the level-repetition effect between global and local responses for each of the distractor conditions. Means were calculated by subtracting fixed attention from switching attention to find the level-repetition effect size for each participant (Table 5). A two-factor

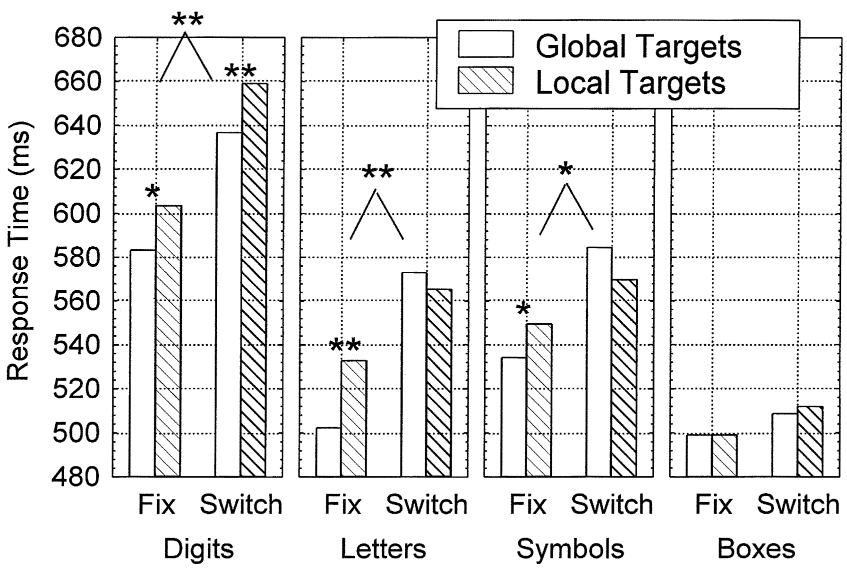

Figure 6. Differences in response times to global and local targets are illustrated for each of the four distractor conditions (digits/letters/symbols/boxes) comparing fixed vs switching attention. $*p < .05$; $**p < .01$.

an attention-switching block) to the position of the ''1'' on odd numbered trials and to the position of the ''2'' on even numbered trials. This instructional cue remained on the screen until the spacebar was pressed to start the block. At the attended level, digits were then presented in increasing sequence except for target trials to which a response was required. In each column, the fourth trial is an example of a target trial. Column A: A subset of the 81 digit-distractor stimuli; example of fixed attention to the global level. Column B: A subset of the 162 letter-distractor stimuli; example of fixed attention to the local level. Column C: A subset of the 162 symbol-distractor stimuli; example of attention alternating between global and local levels, beginning with global. Column D: A subset of the 18 box-distractor stimuli; example of attention alternating between global and local levels, beginning with local.

TABLE 4
Experiment 2: Accuracy expressed as A′ and response time. Mean and standard error of the mean for each distractor group, contrasting attention to level (global/local) × switching levels (fixed/switching)

	Distractor type							
	Digits		*Letters*		*Symbols*		*Boxes*	
	M	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
A′								
Fixed								
Global	.990	.003	.995	.003	.995	.002	.997	.001
Local	.985	.004	.994	.002	.994	.002	.992	.004
Switching								
Global	.918	.016	.966	.010	.971	.006	.992	.003
Local	.915	.020	.968	.010	.980	.005	.993	.003
RT (ms)								
Fixed								
Global	583	13	502	11	534	12	499	8
Local	603	13	533	11	549	12	499	8
Switching								
Global	637	16	573	16	584	16	508	9
Local	659	20	565	14	570	12	512	8

TABLE 5
Experiment 2: Mean RT (ms) and standard error of the mean for each distractor group, comparing the level-repetition effect for global and local responses (Level-repetition effect = Switching − Fixed)

	Distractor type							
	Digits		*Letters*		*Symbols*		*Boxes*	
	M	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Global level-repetition effect	54	8	71	9	50	8	10	5
Local level-repetition effect	55	16	33	9	20	4	13	6

4 (Distractor Category) × 2 (Level-Repetition Effect, global vs local) repeated measures ANOVA was performed.

Level-repetition effect. There was an overall advantage for level repetition as responses were faster and more accurate when attention was not alternating between levels, Switching Levels RT: $F(1, 68) = 115.9$, $p < .00001$; A′: $F(1, 68) = 36.7$, $p < .00001$. Both global and local responses showed the level-repetition effect ($p < .001$). During the blocks when attention was fixed at a level, global responses were faster than local responses ($p < .001$), but this global advantage was not apparent during attention-switching blocks, Newman-Keuls $p = .8$; Level RT: $F(1, 68) = 8.9$, $p < .01$; Level × Switching Levels RT: $F(1, 68) = 9.3$, $p < .01$.

Distractor-variability effect and level repetition. Distractor category was significant for RT and accuracy, RT: $F(3, 68) = 18.5$, $p < .00001$; A′: $F(3, 68) = 12.1$, $p < .0001$. Digit distractors resulted in slower responses than letter, symbol, and box distractors ($p < .001$), and letter and symbol distractors produced slower responses than box distractors ($p < .02$).

Distractor category interacted with switching levels, RT: $F(3, 68) = 7.8$, $p < .001$; A′: $F(3, 68) = 8.6$, $p < .0001$, such that level repetition resulted in faster responses for digit ($p < .001$), letter ($p < .001$), and symbol distractors ($p < .01$), but not box distractors ($p = .3$), and level repetition produced higher accuracy for digit distractors ($p < .01$).

Distractor category also interacted with level, RT: $F(3, 68) = 2.8$, $p < .05$; this revealed that the global advantage (faster responses to global than local) was significant only for digit distractors ($p < .02$). There was no global advantage for box distractors. Moreover, the global advantage that occurred for letter and symbol distractors when attention was fixed disappeared or even tended to reverse to a local advantage when attention switched between global and local levels. The three-way interaction, RT: $F(3, 68) = 4.2$, $p < .01$, confirmed this pattern of results when one compares the global/local difference during attention fixed and switching trials across all the distractor conditions (Figure 6). Global responses were faster than local for digit distractors regardless of whether attention was fixed or switching, and for letter and symbol distractors only when attention was fixed ($p < .05$). There was no significant difference between global and local responses for any of the box distractor conditions, or for letter and symbol distractors when attention was switching ($p > .2$).

An additional analysis looked more closely at the level-repetition effect across distractor conditions to determine whether the size of the effect (Switching − Fixed) differed significantly between global and local responses (Table 5). There was a main effect of distractor category, $F(3, 68) = 7.8$, $MSE = 14173$, $p < .001$, a main effect of level repetition, $F(1, 68) = 9.3$, $MSE = 8981$, $p < .01$, and an interaction, $F(3, 68) = 4.2$, $MSE = 4068$, $p < .01$. In the digit-distractor condition, the effect size was equal for global and local processing (global 54 ms vs local 55 ms, $p = .9$), consistent with the literature on the symmetry of the level-repetition effect. There was no level-repetition effect in the box-distractor condition and no difference between the means for global and local effect sizes (global 10 ms vs local 13 ms, $p = .7$). In contrast, the effect was not symmetric in the letter (global 71 ms vs local 33 ms, $p < .01$) or symbol (global 50 ms vs local 20 ms, $p < .02$) conditions.

In summary, the level-repetition effect was eliminated when distracting information at the ignored level was held constant from trial to trial (box distractors), replicating the results from Experiment 1. The new contribution is to demonstrate that simple featural variation is enough to produce the advantage of level repetition. Whether distracting information was easily categorized (letter distractors) or unfamiliar and meaningless (symbol distractors), there was a strong disadvantage in response time when attention alternated between levels. Moreover, unlike many results reported in the literature, the level repetition effect was not equal for global and local items. We will first address the latter result.

The level-repetition effect is not always symmetric. Many studies have shown that the advantage of level repetition occurs equally for global and local responses. For example, Hubner (2000) observed a robust effect of global dominance, in terms of faster global responses and greater global than local interference (Navon, 1977, 1981), but importantly he also found that the within-trial asymmetric interference did not alter level-repetition effects. That is, level-repetition effects were of the same magnitude for global and local items (see also Robertson, 1996; Robertson et al., 1993a; Ward, 1982). This is an interesting result because if global processing is dominant and occurs with some priority over local, then one might predict that the local-to-global switch would be more efficient. However, switching levels appears to delay processing equally in both directions (Hubner, 2000).

Our results showed the classic effects of global dominance, but importantly level repetition affected global and local targets equally in the digit-distractor condition, not at all in the box-distractor condition, and unequally in the letter- and symbol-distractor conditions. Thus, level-repetition effects are not always of the same magnitude for global and local targets. In the letter- and symbol-distractor conditions, the level-repetition effect was much larger for global responses, eliminating the strong global advantage when attention was alternating between levels. How might we interpret this?

There are two aspects we must address. The first is why the level-repetition effect differs between the digit-distractor and the letter/symbol-distractor conditions. The second is why the effect is asymmetric in the letter/symbol-distractor conditions. The set of all possible compound stimuli in the letter- and symbol-distractor conditions was quite large (162 in each set). The distracting items were never mapped to a response but they were highly variable in terms of features from trial to trial. This featural variation may have been significant in its interaction with the level-repetition effect. One framework within which to think about the distractor category influence is the distinction between Stroop-type interference and Garner-type interference (Pomerantz, 1983). In both cases, there is conflict between two competing streams of information. Stroop-type interference occurs when the information at the irrelevant level is incongruent with the target information and usually implies that the conflict occurs based on the meaning of the competing items (e.g., the word ‘‘blue’’ when naming the red ink, for a review see MacLeod, 1991); Garner-type interference usually implies that the conflict occurs at a much earlier stage of processing, when there is a relatively large amount of unexplained variance at the irrelevant level (Garner, 1974; Pomerantz & Garner, 1973). When most of the variance in the visual stimulus occurs on the relevant dimension (or level), that variance can be incorporated into the variance of responses. However, when the variance occurs on the irrelevant dimension (or level), then before a response can be determined the stimulus must first be analysed to determine what part of the variance is response relevant (Ward, 1983).

For all three of digit-, letter-, and symbol-distractor conditions, the featural variability at the ignored level contributed to Garner-type interference. However, the semantic content of the distractor sets differed and thus the contribution of Stroop-type interference also differed. In the symbol condition, there was a high degree of feature variability at the ignored level from trial to trial, and this variability could not be categorized or easily named. This produced Garner-type interference only. In the letter condition, there was also a high degree of feature variability at the ignored level; however, this variability could be easily categorized and named, and this should have produced an advantage over the symbol-distractor condition if it provided the ability to more easily discount distractors that were easily categorized as non-targets. However, this did not occur. Performance in the letter distractor condition was highly similar to the symbol distractor condition. Given that there was no Stroop-type interference from letter distractors, Garner-type interference may have dominated. In the digit-distractor condition, Garner-type interference was also present; however, given that the distractors were the of same category (and drawn from the same stimulus set) as the targets, Stroop-type interference added significantly to the difficulty, producing the slowest response times overall.

We think that Stroop-type interference in the digit-distractor condition produces the usually observed symmetry because it affects local and global elements equally. We think that Garner-type interference is responsible for the asymmetry in the level-repetition effect in the letter- and symbol-distractor conditions. One way this might work is if the ease or automaticity of processing global compared to local elements (as evidenced by global dominance) makes global processing more sensitive than local processing when controlled attention switching is required.[2] In the absence of Stroop-type interference, global responses may be more affected by the featural variability (Garner-type interference) at the local level because of this increased sensitivity. We test this hypothesis in Experiment 3.

The level-repetition effect does not always occur. Another important observation from Experiment 2 is that no level-repetition effect was observed

[2] Thanks to Lilach Shalev for suggesting this possibility.

when distractors were invariable boxes, replicating our observations from Experiment 1. Lamb and Yund (1996) proposed that the advantage of level repetition is due to activation or priming of level-specific neural mechanisms. Our results suggest that selection alone is not enough to produce the level-repetition effect; simple featural variability at the ignored level is also necessary.

Given that the box-distractor condition reduced the advantage of level repetition to such a degree, we wondered whether there might be some aspect of attentional control that contributed to this result. Even though evidence suggests that predictability of the target level should not affect the advantage of level repetition, this evidence is based on the persistence of the effect. Although level-specific mechanisms can be activated voluntarily in response to instructions, benefit from level repetition does not appear to be subject to voluntary control (Hubner, 2000; Lamb et al., 1998; Lamb & Robertson, 1988; Lamb & Yund, 2000; Ward, 1982). For example, the level-repetition effect is not sensitive to the predictability of the target level (Lamb et al., 1998; Robertson, 1996), suggesting that attentional control does not overcome the automatic effect of level repetition. In the Lamb et al. (1998) study, the target level was either constant, random, or alternating from trial to trial within a block. The predictability of target level in the constant and alternating conditions did not result in a processing advantage over the random level condition, even though the size of the level repetition effect increased with the proportion of level repetitions, from 0.0 (alternating) to 0.5 (random) to 1.0 (constant). Hubner (2000) provided additional evidence that attentional control strategies do not play a role in the level repetition effect by presenting targets at both levels simultaneously, requiring a more task-directed top-down control of selection of the cued level. Three repetition conditions were compared, constant, random, and alternating levels. However, in contrast to Lamb et al. (1998), the alternating condition consisted of a clever manipulation of successive runs of two at each level (i.e., two global targets followed by two local targets). This produced the same frequency of level repetition in both the random and alternating conditions. Target onset was under observer control so that both preparation time and response time could be analysed separately. The results showed a remarkable persistence of level repetition effects. Even under conditions designed to enhance attentional control of level selection, responses were faster when the target level repeated regardless of advanced preparation time or level predictability.

In each of these studies, predictability did not eliminate the level-repetition effect. We eliminated the level-repetition effect in the invariable distractor condition, which also happened to involve predictable target levels. Is the absence of a level-repetition effect in the box-distractor condition at all dependent on the predictability of the target level, or is distractor variability enough to explain the absence?

EXPERIMENT 3

In Experiments 1 and 2, both fixed and switching conditions were ordered so that observers knew ahead of time to which level to direct attention on each trial. Experiment 3 compared the ordered design with a random design in which the level of the to-be-attended digits in the digit sequence task was randomly determined from trial to trial. In addition to comparing predictable with random target level, this design offers the ability to examine level-repetition effects across a sequence of trials within a block, in contrast to the between-block comparisons in Experiments 1 and 2.

Logically, it is difficult to use the digit distractors in the digit-sequence task in a random design, because it would be impossible for participants to distinguish between a digit distractor and an out-of-sequence target if location is not known. Therefore, the distractor category factor compared box distractors with letter distractors. Half of the blocks replicated the ordered presentation of target level as in Experiment 2, and the other half followed a random presentation. One question we addressed was whether the absence of the level-repetition effect in the box-distractor condition would maintain when the target level was not predictable. Note that when target level is not predictable, attention will not likely be focused on the global or local level as it is in the ordered condition. Rather, when the upcoming level is unknown, attention may be distributed across both levels. Other results suggest that the level-repetition effect is automatic (Hubner, 2000; Lamb et al., 1998; Lamb & Robertson, 1988; Lamb & Yund, 2000; Ward, 1982); however we have shown that the level-repetition effect does not occur in the box-distractor condition, so the question here is whether the controlled switching in Experiments 1 and 2 contributed to this absence. If we do not observe an effect of level repetition in the box condition when target level is not predictable, then the claim is that task-directed attentional control processes are not entirely responsible for the lack of the level-repetition effect.

Another question we addressed with Experiment 3 was whether the asymmetry of the level-repetition effect would maintain in the letter-distractor condition when target level was random. If controlled attention affects global to a greater degree than local processing, then the asymmetry should be reduced when observers cannot predict target level.

Method

Participants

Participants were 40 undergraduate students at McMaster University, participating for class credit. All participants were right handed as determined by a handedness questionnaire which consisted of a subset of questions drawn from the Edinburgh Inventory for handedness (Oldfield, 1971). All participants had normal or corrected to normal vision. The 40 observers were distributed across the two distractor conditions.

Stimuli, design, and procedure

The stimuli for the letter- and box-distractor conditions were the same as used in Experiment 2. There were two types of distractors (letters and boxes), two levels (global and local), two attention states for level (repeat and switch), and two predictability states for level (ordered and random). Note that in Experiments 1 and 2, we called the attention states for level ''fixed'' and ''switching''. We use ''repeat'' and ''switch'' here instead to allow for the fact that attention may be distributed across levels in the random condition and is certainly not ''fixed'' at a level for the duration of a block. The distractor variable was a between-subject manipulation; all the other variables were within-subject manipulations. There were five different block types: Four were ordered (replicating Experiment 2) and one was random. Of the four ordered block types, two consisted of level-repetition trials in which the attended level was repeated at the global or local level for the whole block, and two consisted of level-switching trials in which the attended level alternated between global and local elements. In the random block type, the attended level (at which the digit was presented) occurred randomly from trial to trial within blocks. Observers saw 20 ordered blocks (four of each of the four ordered block types) and 20 random blocks. The first eight blocks (four ordered and four random) were considered practice. The order of block presentation after the practice blocks was randomized. All other aspects of the procedure were the same as Experiment 2.

Results and discussion

The manipulations resulted in a four-factor $2 \times 2 \times 2 \times 2$ design (Between-Subject factor) Distractor Category (letters/boxes) $\times$ (Within-Subject factors) Level (global/local) $\times$ Switching Levels (repeat/switch) $\times$ Predictability (ordered/random). Repeated measures ANOVA was used to analyse RT as well as accuracy calculated as A′. Post hoc comparisons of means used the Newman-Keuls test. Figure 7 provides illustrative details of the results of the RT analysis and Table 6 provides the means from the RT and A′ analyses. Table 7 shows the means for the size of the level-repetition effect (switch − repeat level).

The level-repetition effect replicated, showing that response times and accuracy of responses were superior when the attended level repeated, Switching Levels RT: $F(1, 38) = 67.73$, $MSE = 69973$, $p < .000001$; A′ $F(1, 38) = 14.06$, $MSE = .015341$, $p < .001$. Responses were faster and more accurate for box distractors than for letter distractors, Distractor Category RT: $F(1, 38) = 28.29$, $MSE = 351969$, $p < .00001$; A′ $F(1, 38) = 20.92$, $MSE = .07857$, $p < .0001$. Faster and more accurate responses were also obtained when target level could be predicted, Predictability RT: $F(1, 38) = 31.76$, $MSE = 104368$, $p < .00001$;

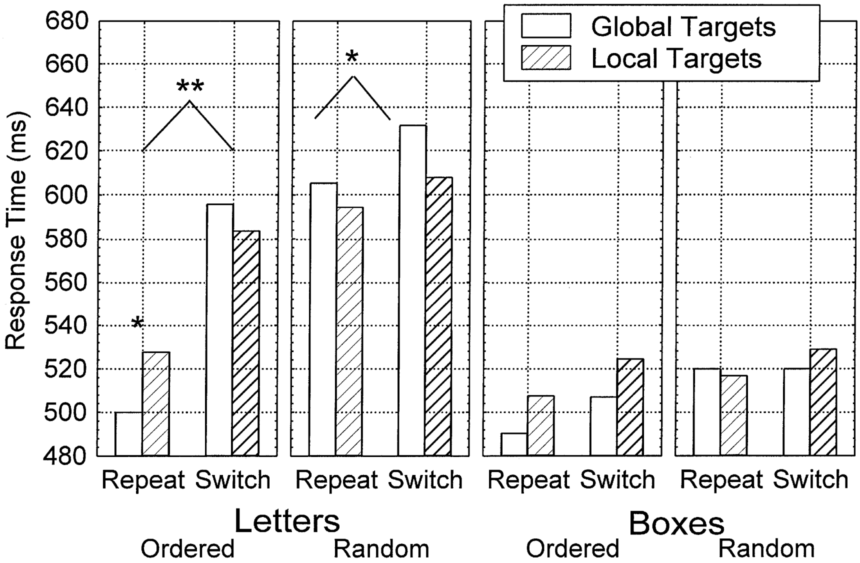

Figure 7. Differences in response times to global and local targets are illustrated for each of the two distractor conditions (letters/boxes) comparing repeat vs switch levels when target position was ordered vs random. *$p < .05$; **$p < .01$.

A′: $F(1, 38) = 18.57$, $MSE = 0.021313$; $p < .001$. There was also an interaction between predictability and switching levels, showing that overall, the level-repetition effect was larger when the target level was predictable, RT: $F(1, 38) = 18.60$, $MSE = 21959$, $p < .001$; A′: $F(1, 38) = 5.78$, $MSE = 0.00397$, $p < .03$.

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The interactions supported the hypothesis that the main effects were due to performance in the letter-distractor condition. When distractors were boxes, no significant effect of target level predictability or level repetition occurred. This was supported by interactions between distractor category and predictability, RT: $F(1, 38) = 11.96$, $MSE = 39290$, $p < .01$; A′: $F(1, 38) = 9.14$, $MSE =$

TABLE 6
Experiment 3: Accuracy expressed as A′ and response time. Mean and standard error of the mean for each distractor group, contrasting Attention to Level (global/local) × Switching Levels (repeat/switching) × Attended Position (ordered/random)

	Distractor type			
	Letters		*Boxes*	
	M	*SE*	*M*	*SE*
A′				
Ordered				
Repeat				
Global	0.99	0.001	1.00	0.001
Local	0.99	0.003	0.99	0.007
Switching				
Global	0.96	0.010	0.99	0.003
Local	0.95	0.011	1.00	0.001
Random				
Repeat				
Global	0.94	0.014	0.99	0.004
Local	0.96	0.007	0.99	0.007
Switching				
Global	0.95	0.008	0.99	0.004
Local	0.93	0.013	0.99	0.004
RT (ms)				
Ordered				
Repeat				
Global	500	10	491	11
Local	527	12	508	8
Switching				
Global	596	10	507	9
Local	583	10	525	13
Random				
Repeat				
Global	605	15	520	9
Local	595	17	517	9
Switching				
Global	632	14	520	11
Local	608	15	529	9

0.010489, $p < .01$, distractor category and switching levels, RT: $F(1, 38) = 25.48$, $MSE = 26325$, $p < .00001$; A′: $F(1, 38) = 12.70$, $MSE = 0.01385$, $p < .01$, and Distractor Category × Predictability × Switching Levels, RT: $F(1, 38) = 8.65$, $MSE = 10210$, $p < .01$; A′ $F(1, 38) = 4.72$, $MSE = 0.00324$, $p < .05$.

Post hoc comparison of response time means using Newman-Keuls confirmed a large level-repetition effect for letter distractors when target position

TABLE 7
Experiment 3: Mean RT (ms) and standard error of the mean for each distractor group, comparing the level-repetition effect for global and local responses (Level-repetition effect = Switch − Repeat)

	Distractor type			
	Letters		*Boxes*	
	M	*SE*	*M*	*SE*
Ordered				
Global level-repetition effect	95	11	16	7
Local level-repetition effect	56	9	17	10
Random				
Global level-repetition effect	27	13	0	7
Local level-repetition effect	13	15	13	9

was predictable (p < .001), and a smaller level-repetition effect for letter distractors when target position was random, significant only for global targets (p < .05), and not for local targets (p = .6). The level-repetition effect was not significant for ordered (p > .2) or random (p > .8) target position when distractors were boxes. A similar pattern occurred for accuracy. Responses were most accurate in the letter-distractor condition when target level repeated and was predictable (p < .01), and this effect was smaller when target position was random, significant only for local targets (p < .01) and not for global targets (p > .4). There was no level-repetition effect on accuracy for ordered or random target position when distractors were boxes (p > .8).

Responses to global targets were faster and more accurate than local targets, but only for level-repetition trials, only for letter distractors, and only when target position was predictable (p = .05), Distractor Category × Level RT: $F(1, 38) = 5.53$, $MSE = 4572$, $p < .05$; Distractor Category × Level × Switching Levels A′: $F(1, 38) = 6.23$, $MSE = 0.003924$, $p < .02$; Distractor Category × Level × Switching Levels RT: $F(1, 38) = 5.22$, MSE 5531, $p < .05$; Predictability × Level RT: $F(1, 38) = 10.02$, $MSE = 7807$, $p < .01$. Global and local responses did not differ in the letter distractor condition when target level was not predictable (p = .25).

An analysis was performed to look more closely at the asymmetry of the size of the level-repetition effect (Switch − Repeat) between global and local responses in the letter distractor condition, to see whether the asymmetry observed in Experiment 2 replicated for ordered and random location conditions (Table 7). A three-factor repeated measures ANOVA looked at Distractor Category (letters/boxes) × Predictability (ordered/random) × Level-Repetition Effect (global/local). There was a main effect of distractor category, which showed the effect was larger for letter distractors, $F(1, 38) = 25.48$, MSE =

52649, $p < .0001$, a main effect of predictability showing that the effect was larger for predictable target levels, $F(1, 38) = 18.6$, $MSE = 43917$, $p < .001$, and an interaction between distractor category and predictability, showing that the difference for predictability occurred only in the letter-distractor condition, $F(1, 38) = 8.65$, $MSE = 20420$, $p < .01$. There was also an significant interaction between distractor category and level-repetition effect, $F(1, 38) = 5.22$, $MSE = 11063$, $p < .03$. The difference between global and local responses was not significant for either ordered (global 16 ms vs local 17 ms; $p = .97$) or random (global 0 ms vs local 13 ms; $p = .4$) target level when distractor were boxes. In the letter-distractor condition, there was a difference in the size of the level-repetition effect when target level was predictable, replicating Experiment 2 (global 95 ms vs local 56 ms; $p < .01$). Although the global level-repetition effect size was larger than the local level-repetition effect size for letter distractors, the difference between them was not significant when target level was random (global 27 ms vs local 13 ms; $p = .8$).

Experiment 3 asked whether the level-repetition effect would be asymmetric in the letter distractor condition when the target level was random from trial to trial. We hypothesized that task-directed controlled attention was greatly reduced in the random condition. The global/local asymmetry in the magnitude of the effect replicated Experiment 2 when the level of the target was predictable. However, when observers could not predict the location of the target, the asymmetry of the level-repetition effect was much reduced. In other words, even though the level-repetition effect was significant for global responses and not for local responses in the random condition (from the main analysis); there was no significant difference between the size of the level-repetition effect for global vs local responses (from the effect-size analysis). On one hand, the data support a hypothesis that imposing attentional control affects global processing more than local, possibly due to the more automatic nature of global processing, and that this sensitivity allows greater interference from the Garner-type irrelevant variance at the distractor level. On the other hand, global processing was more affected by level shifting than local processing in both the ordered and random switching conditions, so there appears to be some asymmetry in the effect even though the difference in magnitude was not significant.

It may be revealing that the largest magnitude difference (105 ms) occurs between predictable (500 ms) and nonpredictable (605 ms) global-level repetitions. Global processing is clearly more affected when target level is not predictable, even when the attended level repeated. From this perspective, global processing is more sensitive to Garner-type interference than is local processing when level shifting is required within a block of trials, whether or not the target level is predictable. The asymmetry is consistent with the idea that task-set inertia plays a role in the level-repetition advantage (Hubner, 2000; Rogers & Monsell, 1995) if one considers that there might be a difference between the distractor sets in their potential to activate irrelevant task sets. It is possible that the letter and symbol distractors tend to activate the local-processing task set to a greater extent than the global-processing task set due to the variable features which might elicit more local examination of stimulus elements. For this hypothesis to work, it is important that task-set inertia is not dependent on top-down attentional control, but that it is tied to stimulus-related processing that can not occur until the stimulus appears. For example, even when the shift is predictable and the onset of the stimulus is entirely under observer control, there is still a cost to task switching (Rogers & Monsell, 1995) and to level switching (Hubner, 2000).

Experiment 3 also asked whether the difference between the letter- and box-distractor conditions would change depending on whether the target level was predictable. One would expect that influence from controlled attention would be reduced in the random condition, and that if controlled attention contributed to the efficiency of processing in the box-distractor condition when target position was predictable, that the random condition should remove that control and show a level-repetition effect. This did not occur; the absence of the level-repetition effect was replicated for the box-distractor condition for both ordered and random level processing.

It should be pointed out that there was an overall cost to performance in the letter-distractor condition when the attended level was random. This could be due in part to the difference between focused (when level was predictable) and distributed (when level was not predictable) attention. It might be argued that the cost related to distributed (as opposed to focused) attention masked any level-repetition effect that might have occurred in the random condition when distractors were boxes. Further experiments are needed to test this hypothesis. However, an important point is that if there was an effect of focused vs distributed attention in the box-distractor condition, it did not produce significant differences in performance between ordered and random level processing. Thus, we suggest that it is not likely that the disadvantage of distributed attention is masking a level-repetition effect in the box-distractor condition. If the difference between focused vs distributed attention is contributing to the overall cost when level is not predictable (letter distractors), then perhaps the larger level repetition effect (predictable vs not predictable level) (Table 7) occurs because attention is focused on the expected level when level is predictable. In that case, we might speculate that the absence of the level repetition effect when filtering is not necessary (box distractors), whether or not level is predictable, is due in part to attention being distributed. When no filtering of the irrelevant level is required, it may be easier to distribute attention than to focus attention on the expected level even when level is predictable. In any case, we conclude that the results of Experiment 3 confirmed that the absence of a level-repetition effect in the box-distractor condition is not dependent on the predictability of target level. The contrast between the letter- and box-distractor conditions replicates the results from Experiments 1 and 2, supporting the hypothesis that the level-repetition effect is sensitive to distractor variability.

SUMMARY

These experiments examined the sensitivity of the level-repetition effect as it interacts with the distractor-variability effect by comparing fixed (level repeated) and switching attention between global and local levels of compound figures. Performance was compared for blocks in which attention was fixed at the global or local level or switched between global and local levels in an ordered (Experiments 1 and 2) or random (Experiment 3) manner. In all cases, the variability at the distractor level was an important manipulation. Comparing invariable box distractors to variable digit (Experiments 1 and 2), letter (Experiments 2 and 3), and symbol (Experiment 2) distractors, we found that a level-repetition advantage was observed for all conditions except the box-distractor condition, and that the effect was asymmetric for the letter and symbol distractor conditions.

We have suggested that there are two types of interference apparent in these results, Stroop-type interference that affects the digit-distractor condition, and Garner-type interference that affects the digit, letter, and symbol distractor conditions. Stroop-type interference affects global and local responses equally, producing a symmetrical level-repetition effect. Garner-type interference affects global responses to a greater degree than local responses, producing an asymmetry in the magnitude of the level-repetition effect. This asymmetry is reduced, but not entirely eliminated, when the target level can not be predicted. On one hand, this supports a hypothesis that the asymmetry may be affected by a greater sensitivity of the more automatic global vs local processing when controlled attention switching is required. On the other hand, global processing may be more sensitive to Garner-type distractor interference than local processing whether or not target level is predictable because the unexplained variance at the global or local distractor level results in a greater tendency to inspect local elements.

We also claim that the level-repetition effect is eliminated or at least greatly reduced when there is little or no interference from the irrelevant level. These results, and the results from brain-imaging studies (Evans et al., 2000), suggest that even though automatic activation of level-specific mechanisms occurs when global or local information is processed, this activation does not lead to the level-repetition effect unless there is competition from the information at the distractor level. In other words, both global and local mechanisms must be engaged on trial $N-1$ for the level-repetition effect to be observed on trial N. The box distractor condition did not produce the effect because the invariable information at the distractor level did not engage the distractor-level mechanisms to provide this competition.

There are several ways in which the box stimuli differed from the other distractor stimuli. One is the aspect we consider to be most important, the neutrality and invariability of the features from trial to trial. Another factor is the difference in the number of compound stimuli across the distractor conditions. Letter and symbol stimuli (162) and digit stimuli (81) consist of a much larger set of figures than box stimuli (18). Another way in which the box distractors are different from the other distractors is their simplicity of form. Future experiments should determine which aspects contributed to the neutrality of the box distractors. We predict that the contrast in the number of hierarchical figures in each distractor set is not important to our observations, but that simplicity of the neutral box form is important because a more complex form might provide additional Garner-type interference due to variable positions of the features of the local items that make up individual global items. This remains to be seen. The very neutrality of the box distractors, however defined, eliminated an effect that is observed quite readily with much smaller stimulus sets than we used here. The experiments in this paper show that priming alone does not effectively speed repeated-level responses unless responses are also affected by featural variability at the ignored level.

These results are not inconsistent with the models that propose a categorical stage as one source of the level-repetition effect. The usually observed symmetry of the effect has been thought to be a result of priming, either by differential weighting of spatial frequency channels (Robertson, 1996), by activation or priming of level-specific neural mechanisms (Lamb & Yund, 1996), or by maintaining a task set associated with global or local responses (Hubner, 1997, 2000). In fact, in the digit-distractor condition in Experiment 1, the level-repetition effect we observed was symmetric and likely influenced by Stroop-type interference, which would affect global and local processing equally at a categorical stage of processing. However, the asymmetry (letter/symbol distractors) or absence (box distractors) of the effect suggests that it is not automatic, and that perhaps exogenous influence from the distractor level that is not categorical must be taken into account as a critical component in any model of the level-repetition effect.

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