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Hemispheric Asymmetries for Global and Local Visual Perception: Effects of Stimulus and Task Factors

Galit Yovel
University of Chicago

Iftah Yovel
Northwestern University

Jerre Levy
University of Chicago

Although neurological and physiological studies indicate a right hemisphere superiority in global processing and a left hemisphere superiority in local processing of Navon-type hierarchical letters (D. Navon, 1977), most investigations of lateralized perception in healthy participants report neither asymmetry. In 6 experiments the authors examined the influence of attentional demands, stimulus properties, and mode of response on perceptual asymmetries for global and local perception. Consistent with their theoretical predictions, asymmetries were more robust on divided- than focused-attention tasks and in response to stimuli in which local and global levels were equally salient compared with those with greater global than local saliency. Contrary to their prediction, perceptual asymmetries were not influenced by the complexity of the motor response.

The global configuration of hierarchical stimuli (large shapes composed of small shapes; Navon, 1977) is differentially represented by the right hemisphere (RH) and local elements by the left hemisphere (LH). Such perceptual asymmetries have been shown in studies of patients with unilateral brain damage (for a review, see Robertson & Lamb, 1991), a split-brain patient (Delis, Kramer, & Kiefner, 1988), and brain imaging in healthy individuals (Fink et al., 1997; Martinez et al., 1997). Patients with large heterogeneous unilateral lesions visually match (Delis, Robertson, & Efron, 1986; Robertson & Delis, 1986) or draw from memory (Delis et al., 1986) only the global form of hierarchical stimuli when the LH is damaged and only local elements when the RH is damaged. Delis and colleagues (1988) reported that a split-brain patient draws the global form of hierarchical stimuli with the left hand (controlled by the RH) and local elements with the right hand (controlled by the LH). Recovered patients with focal temporal-parietal unilateral lesions also manifest hemispheric asymmetries in global and local perception of hierarchical stimuli (Lamb & Robertson, 1988; Lamb, Robertson, & Knight, 1989, 1990; Robertson, Lamb, & Knight, 1988). When hierarchical letters are presented centrally, those with left-hemisphere damage have slower reaction times (RTs) to identify local than global target letters, whereas patients with right-hemisphere damage show the reverse (Lamb & Robertson, 1988; Lamb et al., 1989, 1990). Brain imaging studies of healthy participants with positron emission tomography (Fink et al., 1997), functional magnetic resonance (Martinez et al., 1997), or event-related potentials (ERPs; Heinze, Hinrichs, Scholz, Burchert, & Mangun, 1998) confirm an asymmetric role of the RH in processing global form and of the LH in processing local elements.

Although the foregoing observations predict that RTs to lateralized hierarchical letters should favor the RH-LVF (left visual field) for global perception and the LH-RVF (right visual field) for local perception, the majority of published experiments of healthy participants reveal no asymmetry for either global or local perception (see Table 1). A meta-analysis of six studies (Van Kleeck, 1989) suggested an overall advantage for the RH-LVF in global perception and the LH-RVF in local perception, but only one of the six reported both asymmetries (Sergent, 1982), and four reported neither (Alivisatos & Wilding, 1982; Boles, 1984, Experiments 1 and 2; Van Kleeck, 1989). Martin (1979), who measured vocal RTs, found faster LH-RVF responses to local letters but no asymmetry for global responses. Of 10 more recent experiments in six published articles (Blanca Mena, 1992; Blanca, Zalabardo, Garcia-Criado, & Siles, 1994; Boles & Karner, 1996; Brown & Kosslyn, 1995; Hubner, 1997; Robertson, Lamb, & Zaidel, 1993), only 3 reported the predicted asymmetries (Hubner, 1997; Robertson et al., 1993). It is noteworthy that even when an LH-RVF advantage for local perception has been reported, the greater salience of the global form than local elements elicits faster global than local decisions in both visual fields.

Galit Yovel and Jerre Levy, Department of Psychology, University of Chicago; Iftah Yovel, Department of Psychology, Northwestern University.

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Correspondence concerning this article should be addressed to Galit Yovel, who is now at Cognitive Neuroscience Laboratory, Department of Psychology, Northwestern University, 2029 Sheridan Road, Swift Hall #102, Evanston, Illinois 60208-2710. Electronic mail may be sent to gyovel@uchicago.edu.

Table 1
Task Factors Used in Previous Studies of Lateralized Perception of Hierarchical Letters

Study	Finding	Participants	Task	No. of Trials	Exposure duration	Eccentricity (degrees)	Response	Mask
Alivisatos & Wilding, 1982	−	40	Focused[a]					
			Global	48	100	2.2	Two-choice	No
		40	Local	48	100	2.2	Two-choice	No
Boles, 1984								
Exp. 1	−	16	Focused	192	150	0.85; 1.05	Two-choice	No
Exp. 2	−	16	Focused	768	150	2.7	Two-choice	No
Van Kleeck, 1989	−	24	Focused	144	100	1.65	Two-choice	Yes[b]
Blanca Mena, 1992								
Exp. 1	−	19	Divided	96	100	2.19	Two-choice	No
Exp. 2	−	19	Divided	96	100			
Blanca et al., 1994	−	24	Divided	216	50; 100; 200	1.98	Two-choice	No
Brown & Kosslyn, 1995								
Exp. 1	−	33	Divided	Not reported	100	1.23	Two-choice	No
Boles & Karner, 1996								
Exp. 1	−	18	Focused	192	100	2	Two-choice	No
Exp. 2[c]	−	20	Focused	192	100	2	Two-choice	No
Exp. 3	−	15	Focused	192	33; 100	2	Two-choice	No
Martin, 1979	+	16	Focused	144	100	0[d]	Vocal	Yes
Sergent, 1982	+	12	Divided	270	150	0.75	Two-choice	No
Robertson et al., 1993	+	16	Focused	192	100	2.7	Two-choice	No
Hubner, 1997[e]								
Exp. 1	+	8	Focused[f]	2,880	196	0[d]	Two-choice	No
Exp. 2	+	8	Focused	2,880	196	0[d]	Two-choice	No

Note. All studies presented letters in which the global letter is more salient than the local letter (i.e., GS). In the Finding column, + indicates a significant Field × Level interaction; − indicates a nonsignificant Field × Level interaction. Exposure duration is in milliseconds. Eccentricity in visual angles indicates distance from the medial edge to the fixation point. Exp = experiment.
[a] A global–local matching task. [b] A random dot, noise mask. [c] Bilateral presentations with an arrow directing attention to one visual field on any given trial. [d] The inner edge of the stimuli was adjacent to the vertical midline. [e] The study includes, in addition to standard hierarchical letters, high-pass filtered letters. The table indicates the results for only the standard stimuli. [f] A cue indicates the to-be-attended level (global, local) on each trial.

The repeated failures of most studies to reveal hemispheric asymmetries for global and local perception in response to lateralized hierarchical letters stands in contrast to the evidence for these asymmetries in neurological patients or in physiological studies. Because of multiple difficulties in interpreting observations from neurological patients (Robertson, Knight, Rafal, & Shimamura, 1993), physiological measures (Sergent, 1994), and studies of lateralized perception (Sergent & Hellige, 1986), valid conclusions regarding functional hemispheric differences depend on converging evidence from all methods of investigation.

Task and Stimulus Factors

Various combinations of task and stimulus factors (e.g., exposure duration, size, eccentricity, see Hellige & Sergent, 1986) are critical in revealing or concealing perceptual effects of hemispheric differences on lateralized tachistoscopic tasks. Table 1 lists the various task and stimulus factors used in previous experiments on lateralized perception of standard Navon-type hierarchical letters by healthy participants. There are no factors or unique combinations of factors that differentiate the studies with negative outcomes from the minority that reported reliable perceptual asymmetries. For example, Boles and Karner (1996) used task factors that were similar to those used by Robertson et al. (1993) but failed to replicate their findings.

The current studies investigated a global and local discrimination of lateralized hierarchical letters on tasks that varied in perceptual, attentional, or response requirements, some of which were expected to elicit more robust asymmetries than others. We selected fixed parameters (poststimulus mask, small eccentricity) to maximize the perceptual effects of hemispheric asymmetries and to minimize the influence of contaminating factors.

Study 1

Study 1 includes three experiments that examined the influence of the type of hierarchical letter, the attentional task, and the mode of response on perceptual asymmetries for global and local perception.

Varied Task Factors

Hierarchical Letters

All prior reports of lateralized perception presented hierarchical stimuli in which the global level was much more salient than the local level as manifested in faster and more accurate identification of the global than local letter. The much greater ease of discriminating global than local letters might entail ceiling effects on the former (as easy for the LH as RH) and floor effects on the latter (as difficult for the LH as RH). We suggest that hemispheric asymmetries are more likely to generate perceptual asymmetries when the global and local levels of hierarchical letters are equally salient, as indicated by RTs, and when discrimination is intermediate in difficulty between the easy global and difficult local discriminations of classical Navon-type hierarchical letters (Navon, 1977).

To test this hypothesis, we presented two types of hierarchical letters in each experiment, one that was similar to stimuli presented in earlier studies, in which the global letter was more salient than the local letter (global saliency = GS), and a second, in which the two levels were equally salient (ES). The ES stimuli had the same global size as the GS stimuli but had fewer and larger local elements with greater spacing between them (see Figure 1).

Attention Task

Two types of attentional tasks are commonly used in the study of global and local perception, one that requires focused attention and another that requires divided attention. In the focused-attention task, participants search for a target letter at a specified level (global or local) and ignore the other level in a given block of trials. By requiring both hemispheres to adjust their attentional mechanisms to the designated local or global level, the focused-attention task may reduce the effects of hemispheric asymmetries on perception. In the divided-attention task, participants search for a target letter that randomly appears either at the global or the local level, which permits each hemisphere to attend to its preferred level (i.e., global attention for the RH-LVF and local attention for the LH-RVF) on all trials. Thus, on this task one hemisphere would be disadvantaged by the necessity to switch attention from its preferred level to the target level and also by poorer processing of the target once attention is switched. This suggests larger perceptual effects of hemispheric asymmetries on the divided-attention task, which we used in Experiments 1A and 1C, than on the focused-attention task, which we used in Experiment 1B. Consistent with this hypothesis, a recent ERP study reported a larger amplitude of the N250 component over the RH during global perception and over the LH during local perception in a divided- but not in a focused-attention task (Heinze et al., 1998).

Mode of Response

All previous studies of manual RTs to lateralized hierarchical stimuli have used a two-choice response in which each of two classes of stimuli (e.g., two different target letters) maps to one of two response keys. For two reasons, we suggest that perceptual effects of hemispheric asymmetries for local and global processing are likely to be more robust with a go/no-go (GNG) response (Experiments 1A and 1B), in which participants give a fixed response to target stimuli and no response to nontarget stimuli, than with a two-choice response (Experiment 1C). First, two-choice, but not GNG, RTs are subject to spatial-compatibility effects (i.e., faster responses to LVF than RVF stimuli with the left key and faster responses to RVF than LVF stimuli with the right key, (Berlucchi, Crea, di Stefano, & Tassinari, 1977; Hommel, 1994; Simon, 1990), which could partially conceal perceptual effects of hemispheric asymmetries. Second, because the LH is specialized for motor planning and praxis (Kimura & Archibald, 1974), perceptual effects of hemispheric asymmetries in local and global processing may be less contaminated by motor asymmetries on the simpler GNG task than on the more complex two-choice task.

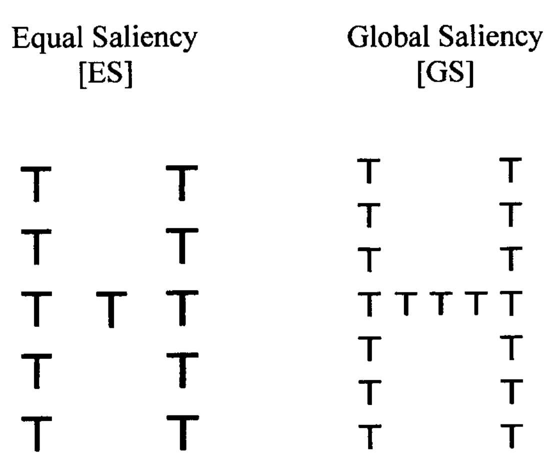

Figure 1. Two types of hierarchical letters were presented in Study 1: equal saliency (ES) letters, in which the global and the local levels are equally salient, and global saliency (GS) stimuli, in which the global letter is more salient than the local letter, as indicated by performance (see Figure 3).

Fixed Task Factors

Backward Masking

Moscovitch and colleagues (Moskovitch 1983, 1988; Moskovitch, Scullion, & Christie, 1976) demonstrated that backward pattern masking of lateralized stimuli interferes with interhemispheric communication of laterally specialized stimulus codes, which emerge in later stages of processing. Because asymmetries of global and local perception reflect later stages of processing (Heinze et al., 1998; Ivry & Robertson, 1998), we used a post-stimulus pattern mask in all experiments to reduce interhemispheric communication and increase the effects of hemispheric asymmetries on perception.

Eccentricity

An RH superiority in identifying visual stimuli of low quality has been shown under a variety of degraded visual conditions (for review, see Christman, 1989; Sergent, 1983). Because stimuli become progressively less perceptible with distance from the fovea, we presented stimuli only 0.5° from fixation to reduce stimulus degradation as much as possible, which could bias or mask the perceptual effects of hemispheric asymmetries. Although peripheral presentation of visual stimuli is an inherent feature of the laterality paradigm, it is not imperative to present the stimuli at eccentricities larger than 0.5° from fixation. Contrary to findings in monkeys that indicated bilateral representation of the central 1.5° of the visual field (Sanderson & Sherman, 1971), studies of healthy human participants (Lines & Milner, 1983), a patient with agenesis of the corpus callosum (Lines, 1984), and split-brain patients (Levy, Trevarthen, & Sperry, 1972) showed that there is no overlap between the nasal and temporal areas of the retina, which project, respectively, to the contralateral and ipsilateral hemispheres.

In summary, all three experiments used a poststimulus mask, presented letters close to fixation, and compared perceptual asymmetries for GS and ES hierarchical letters (Figure 1). In Experiment 1A, we sought to maximize perceptual effects of hemispheric asymmetries by using a divided-attention task and a GNG response. To examine the effect of attentional demands, in Experiment 1B we presented a GNG response, as in Experiment 1A, but required focused attention. To examine the effect of response demands, in Experiment 1C we presented a divided-attention task, as in Experiment 1A, but used a two-choice response.

In Experiment 1A, we also examined discrimination of nonhierarchical single letters of three different sizes to distinguish between effects of target size and level of a target in hierarchical stimuli (Lamb & Robertson, 1988). The sizes were those of the global hierarchical letter (large), local ES letters (medium), and local GS letters (small). Faster RH-LVF responses for large single letters and faster LH-RVF responses for medium and small single letters would indicate that global and local asymmetries are mediated by perceptual asymmetries for absolute size and not their levels in hierarchical stimuli.

General Method for Study 1

Participants

Forty-eight University of Chicago students or employees (age range = 18–38 years), 16 (8 men and 8 women) for each experiment, were paid to participate. Participants completed a nine-item handedness questionnaire on a 5-point scale (1 = *right hand always*, 2 = *right hand mostly*, 3 = *either hand equally*, 4 = *left hand mostly*, 5 = *left hand always*). Only participants who preferred the right hand (score of 1 or 2) on at least eight out of nine items and did not prefer the left hand on any item were recruited. All participants had normal or corrected-to-normal vision (20/20 visual acuity for both near and far vision and normal stereoscopic fusion), as determined by the Titmus Vision Tester.

Stimuli and Apparatus

The hierarchical stimuli were large letters made of small letters (Navon, 1977). Targets were *H* and *T* and nontargets were *E*, *F*, *N*, and *Y*. Each hierarchical stimulus had different letters at the global and the local levels. In GS stimuli, local letters (0.3° × 0.2°) in a 5 column × 7 row array formed a global letter (3.9° × 2.3°). The local/global height and width ratios for GS stimuli were 0.077 and 0.088, respectively. In ES stimuli, local letters (0.5° × 0.4°) in a 3 column × 5 row array formed a global letter (3.9° × 2.3°). The local/global height and width ratios for ES stimuli were 0.128 and 0.174, respectively.

The letters were black on a white background. The medial edges of the stimuli appeared 0.5° to the right or left of a fixation point. A poststimulus pattern mask consisting of two 9 column × 8 row matrices (each matrix, 3° in width and 3.9° in height) of small letters (0.15° × 0.1°) were presented simultaneously to the right and the left of a fixation cross. The medial edges of the two matrices were presented 0.5° lateral to the fixation point.

The stimuli were generated and presented on a 15″ monitor (832 × 624, 75Hz, Mac Std Gamma) of a Macintosh Performa 6200CD by PsyScope software (Version 1.2) (Cohen, MacWhinney, Flatt, & Provost, 1993) and were viewed from a distance of 45 cm, which was controlled by a chin rest.

Procedure and Design

The participants were introduced to the experiment by signing a consent form in which they were given general information on the experiment. They then completed the nine-item handedness questionnaire and were tested for near and far visual acuity and stereoscopic fusion. A trial sequence consisted of the appearance of a fixation plus sign for 3 s, a randomly lateralized stimulus presentation for 100 ms, and the poststimulus mask for 1,000 ms. Half of the participants responded with the right hand, and half responded with the left. The intertrial interval was 2 s.

Method for Experiment 1A—Divided GNG

Stimuli. Half the hierarchical stimuli had nontarget letters at the local and global levels (nontarget stimuli), and half had the target *H* or *T* at the local or global level and a nontarget at the other level (target stimuli; see Figure 2). A total of 16 different hierarchical stimuli of each type (GS and ES) were presented, which consisted of 8 different stimuli that contained a target letter (*H* or *T*) either at the global or local level and 8 nontarget stimuli randomly selected from the 12 possible combinations of 4 different nontarget letters.

Procedure. Participants received one block of 128 GS trials and one of 128 ES trials. Each block was preceded by 16 practice trials with feedback on accuracy. The order of GS and ES blocks was counterbalanced over participants. Participants were instructed to press a single response key whenever they detected either of the two target letters at either level and not to respond when neither was present (GNG response).

In addition to the hierarchical-letter task, participants discriminated target from nontarget single letters (*S* trials) either before (half the participants) or after the GS and ES blocks. Targets (*H* and *T*) and nontargets (*E*, *F*, *N*, and *Y*) were the same as for hierarchical stimuli. Single letters the size of GS local, ES local, or global letters of the hierarchical stimuli were presented in three separate blocks of 32 trials/block (half targets) in an order randomized over participants. Participants were asked to press the key whenever either of the two single target letters (*H* or *T*) was presented and not to press when single nontarget letters appeared.

Method for Experiment 1B—Focused GNG

Stimuli. The hierarchical stimuli in Experiment 1B were identical to the target stimuli in Experiment 1A, which contained a target letter (*H* or *T*) at one level and a nontarget at the other. Because attention was directed to a given level, stimuli in which a nontarget letter appeared at the directed level and a target letter at the other level were no-go stimuli in the focused GNG task. For this reason, stimuli in which nontarget letters were present at both the local and global levels (the nontarget stimuli of Experiment 1A) were not included in the focused-attention task.

Procedure and design. Participants received two 64-trial GS blocks and two 64-trial ES blocks, one of each type with attention directed to the local level and the other to the global level. Each block was preceded by 16 practice trials with feedback on accuracy. The order of GS and ES blocks was counterbalanced over participants, as were local and global blocks. As in Experiment 1A, a GNG mode of response was used. Participants were directed to respond if and only if a target letter (either *H* or *T*) appeared at the designated level.

Method for Experiment 1C—Divided Two-Choice

Stimuli. The hierarchical stimuli were the same as those presented in Experiment 1B and always had a target letter at one level.

Procedure and design. Participants received one block of 128 GS trials and one of 128 ES trials. Each block was preceded by 16 practice trials with feedback on accuracy. The order of GS and ES blocks was counterbalanced over participants. Participants were asked to press one key with the index finger when one of the two targets was present at either level and the other key with the middle finger when the other target was present at either level. Hands, keys, and target letters were counterbalanced across participants.

Data Analysis

We performed analyses on correct RTs and their log transformations and on error rates and their arcsine transformations. RTs lower than 250 ms and

Figure 2. A sample of the hierarchical letters that were presented in Experiment 1A. Target letters were *T* and *H*. Participants were instructed to press a single response key whenever they detected either of the two target letters at either level (go response) and not to respond when neither was present (no-go response). Experiments 1B, 1C, and the Two-choice experiments of Study 2 included only hierarchical letters that contained a target letter.

higher than 2,000 ms were excluded from the analysis (approximately 1% of the trials). Because raw and transformed data yielded similar outcomes, we report analyses and figures for the untransformed data.

For the RT analysis, we performed a repeated-measures analysis of variance (ANOVA) with type of stimulus (ES, GS), visual field (RVF, LVF), and level (local, global) as within-subjects factors and sex, response hand, and task (divided GNG, focused GNG, divided two-choice) as between-subjects factors. Because of task differences in experimental designs, the effect of block order and its interaction with the other factors was separately assessed for each task. Because measures of accuracy differed between tasks, we analyzed them separately for the three tasks.

For unpredicted effects, we set alpha at $p = .005$. Because findings in brain-damaged patients and physiological studies predict a global advantage for the RH-LVF and a local advantage for the LH-RVF (Level × Field interaction), we applied planned one-tailed t tests ($p < .05$) to the interaction and simple effects of field and level. Two-tailed tests ($p < .05$) were applied to conceptually predicted effects that have no prior empirical support, which included the Type (GS, ES) × Level (global, local) interaction (fastest RTs to GS global and slowest to GS local, with local and global ES intermediate and equal) and the three-way interaction of type, field, and level and their simple effects (larger LH-RVF advantage for local responses and RH-LVF advantage for global responses to ES than GS stimuli).

Results

Reaction Times

A main effect of task, $F(1, 36) = 13.54$, $p < .001$, indicated longer latencies on the divided two-choice task than on the divided GNG or focused GNG tasks, which did not differ significantly. Although global responses were faster than local responses, $F(1, 36) = 19.71$, $p < .0001$, a Type × Level interaction, $F(1, 36) = 82.98$, $p < .0001$, indicated that responses were faster to the global than the local level only for GS letters, $F(1, 36) = 88.18$, $p < .0001$, whereas for ES letters, global and local responses did not differ, $F(1, 36) = 1.44$, $p = .24$. Additionally, slower ES than GS global responses, $F(1, 36) = 41.04$, $p < .0001$, and faster ES than GS local responses, $F(1, 36) = 27.93$, $p < .0001$, revealed the intermediate level of difficulty of global and local perception of ES letters compared with the easy global and difficult local perception of GS letters (Figure 3).

The Level × Field interaction, $t(36) = 7.57$, $p < .0001$, one-tailed, indicated an RH-LVF advantage for global perception, $t(36) = 4.52$, $p < .0001$, one-tailed, and an LH-RVF advantage for local perception, $t(36) = -4.63$, $p < .0001$, one-tailed. Although the Field × Level interaction was not significantly influenced by stimulus type, $F(1, 36) = 1.61$, $p = .21$; task, $F(2, 36) = 1.92$, $p = .16$; or both together, $F(2, 36) = 1.43$, $p = .25$, its effect size (see Figure 4) was larger for ES than GS letters in all three tasks. The divided GNG task produced the largest effect size for both types of letters. The only task that did not yield a statistically significant Level × Field effect was the focused-attention task for GS letters (see the Appendix for individual ANOVAs for each experiment).

Figure 5 shows that the different task conditions produced different patterns of asymmetry. Only the divided GNG task with ES letters yielded a global advantage in the RH-LVF and a local advantage in the LH-RVF. In the focused GNG and divided two-choice tasks, ES letters elicited no level difference in the RH-LVF and a local advantage in the LH-RVF. In all tasks, GS letters evoked a global advantage in both fields, which was larger in the RH-LVF (see the Appendix for individual ANOVAs for the different tasks and stimulus types).

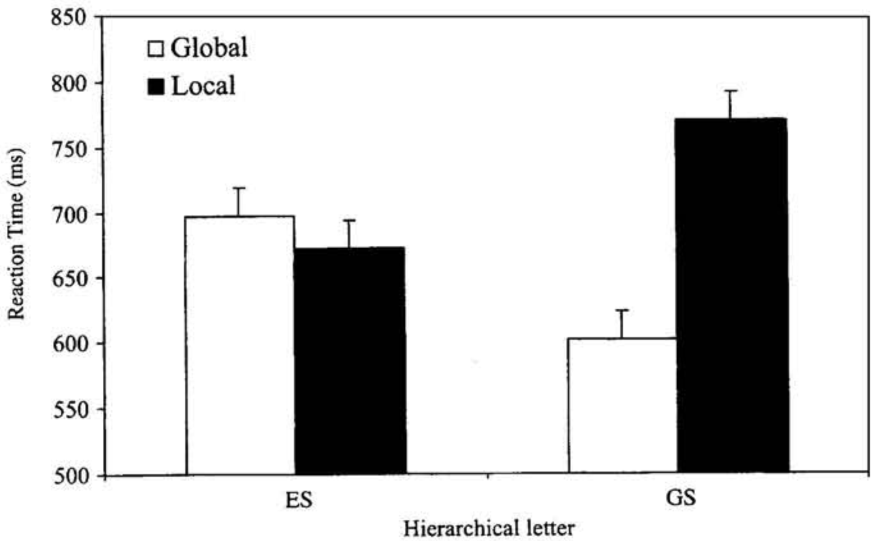

Figure 3. Overall mean reaction times (in milliseconds) to the global and local levels of equal saliency (ES) and global saliency (GS) hierarchical letters in all three experiments of Study 1. There was no significant difference between responses to the global and local level for ES letters. Responses were significantly faster to the global than local level for GS letters. Error bars represent the standard error of the level (global, local) effect for ES (20.28) and GS (17.90) letters.

A significant interaction of level, field, task, and sex, $F(2, 36) = 9.30$, $p = .005$, arose from a Field × Level interaction, $F(1, 12) = 12.56$, $p < .005$, on the divided GNG task that was larger in women, $t(6) = 5.18$, $p < .002$, one-tailed, than in men, $t(6) = 2.16$, $p < .04$, one-tailed, and no influence of sex on the Level × Field interaction on the focused GNG or the divided two-choice tasks. The reliability of this interaction is open to serious question because the effect is neither conceptually nor empirically predicted.

The Effect of Task Factors

To assess the effect of attentional demands, we compared Experiment 1A (divided attention, GNG) and Experiment 1B (focused attention, GNG), which were similar in all task factors except the attentional task. A marginally significant interaction of attentional task, level, and field, $F(1, 24) = 3.22$, $p < .09$, reflected a trend toward a larger Level × Field interaction with divided, $t(24) = 5.59$, $p < .0001$, one-tailed, than focused attention, $t(24) =$

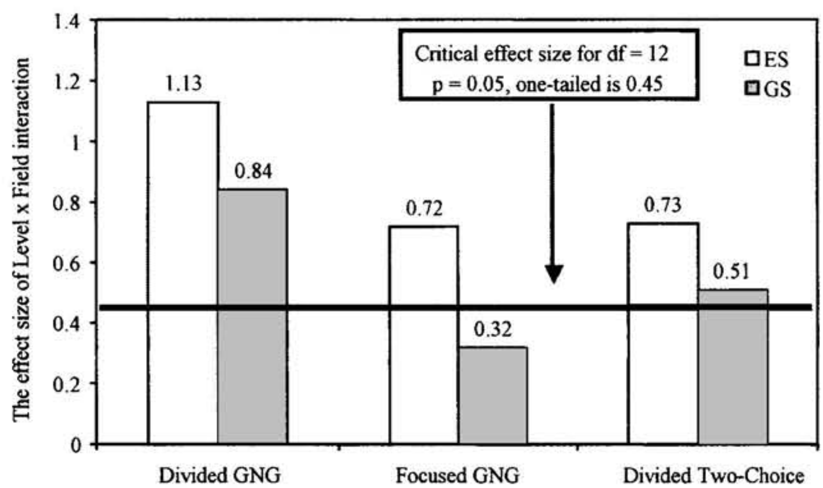

Figure 4. Effect sizes of the Level × Field interaction—[Local (LVF − RVF) − Global (LVF − RVF)]/standard deviation of Level × Field interaction—of the three experiments of Study 1 for equal saliency (ES) and global saliency (GS) hierarchical letters. The critical effect size for $t(12)$, $p = .05$, one-tailed, is 0.45. In all studies, ES letters yielded larger effects than GS letters. LVF = left visual field; RVF = right visual field; GNG = go/no-go.

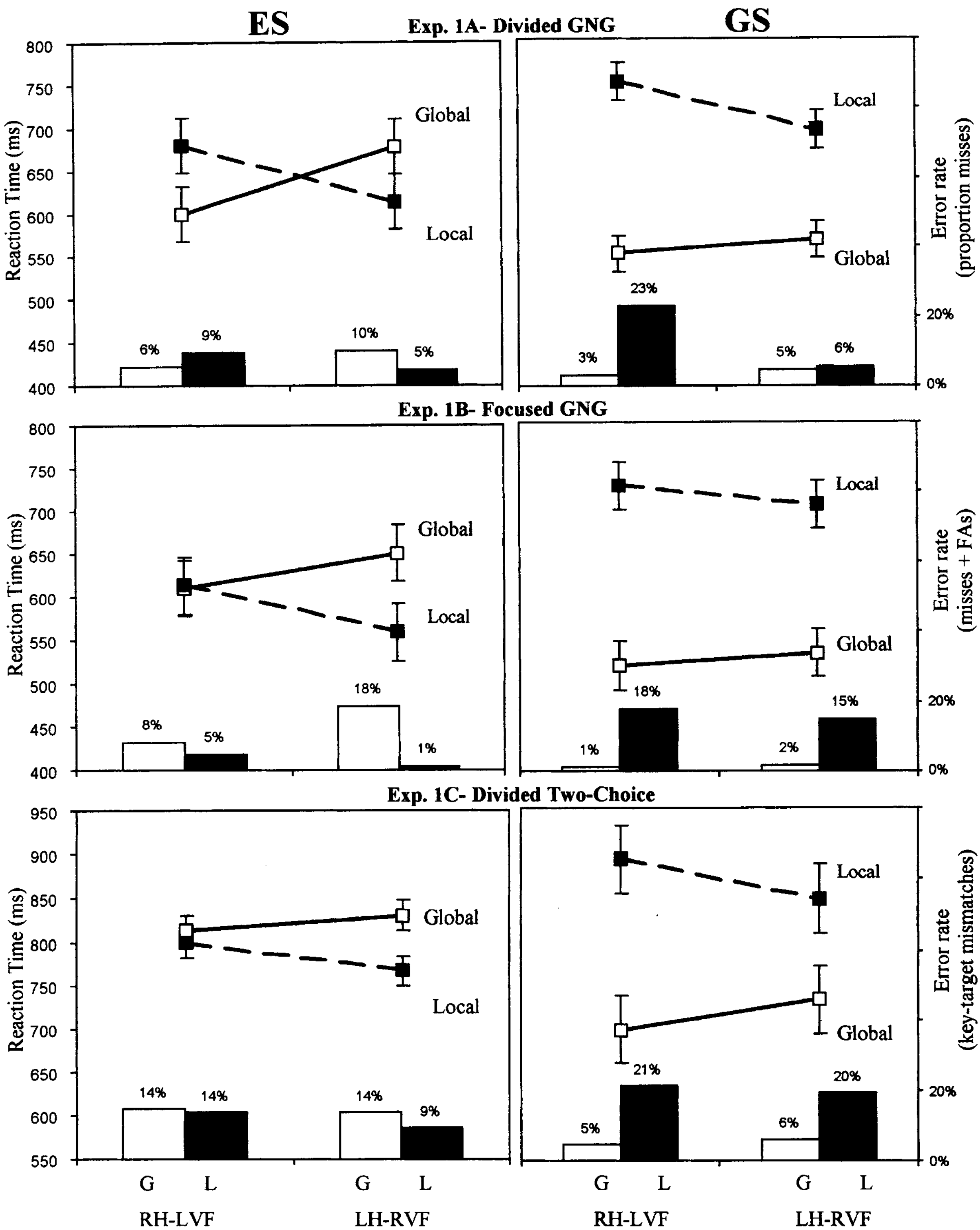

Figure 5. Mean reaction times (in milliseconds) and accuracy levels for global (G) and local (L) levels of equal saliency (ES) and global saliency (GS) hierarchical letters that were presented to the right hemisphere, left visual field (RH-LVF) and the left hemisphere, right visual field (LH-RVF) in the three experiments of Study 1. Error bars represent the standard error of the Level × Field interaction. Exp. 1A: ES = 31.8, GS = 21.6; Exp. 1B: ES = 32.8, GS = 27.5; Exp. 1C: ES = 16.9, GS = 38.8. Exp. = experiment; GNG = go/no-go; FAs = false alarms.

4.61, $p < .0005$, one-tailed (see the Appendix for separate analyses of ES and GS letters in the divided- and the focused-attention tasks). There was no main effect of attention task, $F(1, 24) = 0.50$, $p = .49$, nor any interactions of attention task with any other factors.

To assess the effect of response requirements, we compared Experiment 1A (divided attention, GNG) and Experiment 1C (divided attention, two-choice), which were similar in all task factors except response demands. A main effect of response mode, $F(1, 24) = 18.53$, $p < .0005$, reflected longer latencies in the two-choice task (M = 798 ms) than in the GNG task (M = 642 ms). The Level × Field interaction was not significantly influenced by the type of hierarchical letter, $F(1, 24) = 0.51$, $p = .49$; response mode, $F(1, 24) = 2.46$, $p = .13$; or both together, $F(1, 24) = 2.92$, $p = .10$.

Type of Nontarget Global Letters

The four nontarget letters that were selected for this study were the letters *Y*, *N*, *E*, and *F*. After the completion of the study and the analysis of the results, we were concerned that the LH-RVF advantage for the local level might have emerged solely because of the fact that local letters that formed the global *E* and *F* (biased letters) were located closer to the fixation point (smaller eccentricity) when the biased letters were presented in the LH-RVF than in the RH-LVF. This effect was not expected in *N* and *Y* (unbiased letters) in which local letters were presented at similar eccentricities in the two hemifields. However, a repeated measures ANOVA on the response to local letters, with type of hierarchical stimulus (GS, ES), visual field, and type of nontarget global letter (biased, unbiased) as three within-subjects factors and sex, hand, and task as between-subjects factors, showed no difference between the local LH-RVF advantage for biased and unbiased letters and no interaction with type. Thus, the LH-RVF local advantage for ES or GS stimuli was just as large for unbiased as for biased global letters.

The Effect of Block Order

The effect of block order was examined within each experiment. Neither the effect of block nor any interactions with this factor were significant in any of the three experiments. This finding suggests that practice did not influence the magnitude of perceptual asymmetries for global and local perception.

Single Letters

Responses to single letters were examined in a repeated measures ANOVA with visual field and size of single letters (large, medium, small) as within-subjects factors and sex and hand as between-subjects factors. A significant Field × Size interaction, $F(2, 24) = 8.19$, $p < .002$, reflected no field asymmetries for either large letters $F(1, 12) = 2.57$, $p = .14$, or small letters $F(1, 12) = 0.47$, $p = .51$, and a faster response for the LH-RVF than RH-LVF for medium letters, $F(1, 12) = 10.29$, $p < .008$. The global RH-LVF advantage is evidently not mediated by letter size, nor is the local LH-RVF advantage because this was present even for GS stimuli that are made of small letters.

Error Rate

Because the three experiments had different measures of accuracy for global and local responses in the two visual fields, we analyzed error rates for each experiment separately.

Experiment 1A—divided GNG. Because false alarms (FAs) cannot be assigned to one of the two levels (global, local) on the GNG task, our measure of accuracy includes only the proportion of missed trials for each Level × Field condition. This analysis indicated no evidence for a speed–accuracy trade-off. A Type × Level interaction, $F(1, 12) = 18.44$, $p < .001$, arose from fewer global than local misses for GS letters, $F(1, 12) = 15.87$, $p < .002$, but equal frequencies of global and local misses for ES letters, $F(1, 12) = 0.93$, $p = .35$, which was consistent with RTs. A Field × Level interaction, $t(12) = 3.94$, $p < .001$, one-tailed, reflected fewer global misses in the RH-LVF than the LH-RVF, $t(12) = 1.88$, $p < .04$, one-tailed, and fewer local misses in the LH-RVF than the RH-LVF, $t(12) = -2.46$, $p < .02$, one-tailed. The three-way interaction of type, level, and field was not significant, $F(1, 12) = 0.48$, $p = .64$ (Figure 5). With the factor of level necessarily omitted, an ANOVA on FAs, with field and type (GS, ES) as repeated measures, revealed more frequent FAs in response to ES than GS letters, $F(1, 12) = 39.48$, $p < .0001$, which was the only significant effect. The FA rate in the RH-LVF was 12.5% for GS and 24.8% for ES letters. In the LH-RVF, the FA rate was 13.3% for GS and 27.3% for ES letters.

Experiment 1B—focused GNG. We examined misses, false alarms (FAs), and the discrimination measure d' for global and local responses in the two visual fields. A Type × Level interaction $F(1, 12) = 17.31$, $p < .001$, for misses indicated a global advantage for GS letters, $F(1, 12) = 13.40$, $p < .005$, and a local advantage for ES letters, $F(1, 12) = 10.20$, $p < .01$. Consistent with RT findings, a Level × Field interaction, $t(12) = 4.17$, $p < .001$, one-tailed, showed more misses for global responses in the LH-RVF than the RH-LVF, $t(12) = 4.35$, $p < .0005$, one-tailed and more misses for local responses in the RH-LVF than the LH-RVF, $t(12) = -1.99$, $p < .04$, one-tailed. The three-way interaction of type, level, and field, $F(1, 12) = 5.45$, $p < .04$, indicated a Level × Field interaction for ES, $t(12) = 5.09$, $p < .0002$, one-tailed, but not for GS, $t(12) = 1.17$, $p = .13$, one-tailed, letters.

For FAs, a Type × Level interaction, $F(1, 12) = 90.38$, $p < .0001$, indicated a global advantage for GS letters, $F(1, 12) = 10.64$, $p < .0001$, and a local advantage for ES letters, $F(1, 12) = 58.13$, $p < .0001$. Although the Level × Field interaction was significant, $t(12) = 2.28$, $p < .03$, one-tailed, neither the RH-LVF advantage for global decisions, $t(12) = 1.44$, $p < .09$, one-tailed, nor the LH-RVF advantage for local decisions, $t(12) = -1.55$, $p < .07$, one-tailed, reached conventional levels of significance in simple-effects analyses. The three-way interaction of Type × Level × Field was not significant, $F(1, 12) = 1.59$, $p = .24$.

Analysis of Misses + FAs (see Figure 5) showed a Level × Field interaction, $t(12) = 4.66$, $p < .0005$, one-tailed, which indicated more errors for global responses in the LH-RVF than the RH-LVF, $t(12) = 4.64$, $p < .0005$, one-tailed, and more errors for local responses in the RH-LVF than the LH-RVF, $t(12) = -2.87$, $p < .007$, one-tailed. The three-way interaction of Type × Level × Field was not significant, $F(1, 12) = 0.82$, $p = .38$.

The analysis of d' showed the same interactions of Type × Level, $F(1, 12) = 87.65$, $p < .0001$, and Level × Field, $t(12) = -6.39$, $p < .0001$, one-tailed, as for misses. Global targets were better discriminated than local targets in GS stimuli $F(1, 12) = 27.05$, $p < .0002$, and vice versa for ES stimuli, $F(1, 12) = 54.98$, $p < .0001$. There was an RH-LVF advantage for discriminating global targets, $t(12) = -5.09$, $p < .0002$, one-tailed, and an LH-RVF advantage for discriminating local targets, $t(12) = 3.17$, $p < .004$, one-tailed. The three-way interaction of Type × Level × Field was not significant, $F(1, 12) = 0.60$, $p = .45$.

In summary, consistent with RT findings, global responses were more accurate than local responses in the RH-LVF and vice versa in the LH-RVF. In contrast to RT data, in which the equality of local and global RTs to ES stimuli suggests equal saliency of the two levels, the greater accuracy of local responses to ES stimuli suggests that in the focused-attention task, the local elements were more salient than the global form.

Experiment 1C—divided two-choice. Error rates (wrong key pressed in response to a given target letter) were generally consistent with RT data. A Type × Level interaction, $F(1, 12) = 15.49$, $p < .002$, arose from fewer global than local errors for GS letters, $F(1, 12) = 8.26$, $p < .02$, and equal error frequencies for global and the local levels of ES letters, $F(1, 12) = 0.29$, $p = .60$. A Level × Field interaction, $t(12) = 2.19$, $p < .03$, one-tailed, reflected an LH-RVF advantage for local decisions, $t(12) = -2.58$, $p < .02$, one-tailed, but in contrast to RT data, no asymmetry for global decisions (Figure 5).

Discussion

The RH-LVF advantage for global discriminations and the LH-RVF advantage for local discriminations is consistent with evidence from neurological patients and physiological studies that the RH and LH are specialized, respectively, for global and local processing of visual stimuli. Although the general analysis did not reveal a significant influence of attentional task or response mode on the magnitude of perceptual asymmetries, Figure 4 shows that the divided attention GNG task produced the largest asymmetries. Additionally, the comparison of the divided- and focused-attention GNG tasks (Experiments 1A and 1B) revealed a marginally significant interaction of attention task, level, and field, which reflected larger perceptual asymmetries on the divided than the focused-attention task. Planned comparisons within tasks and stimulus types (see the Appendix) revealed significant Level × Field interactions for both ES and GS letters in the divided-attention task (Experiment 1A), but only for ES letters in the focused-attention task (Experiment 1B).

Three factors may determine the way attention is allocated by each hemisphere in our different tasks: (a) the type of the hierarchical letter, (b) the preferred level of each hemisphere, and (c) the attentional task. The GS letters draw attention to the global level regardless of attentional demands (focused, divided) or visual field and therefore produce faster global than local responses in both visual fields on both the divided- and focused-attention tasks. This global advantage for GS letters is larger within the RH-LVF than LH-RVF, which suggests a stronger bias of the RH than LH to attend to the GS global form. For ES letters, the global configuration is less salient relative to local elements and therefore only the RH, which is superior in the synthesis of global configurations, attends more to the global than to the local level, whereas the LH, which may overlook the global configuration, shows a clear local preference (see Figure 5).

Consistent with our predictions, the attentional task also influences the magnitude of asymmetries for global and local perception. Our results suggest that perceptual asymmetries are weaker on the focused-attention task, in which attention is directed to one specified level, than on the divided-attention task, in which attention must be divided between levels. In particular, if attention is directed to the specified level on the focused-attention task, it is plausible that each hemisphere adjusts its attentional mechanism appropriately according to task demands and that asymmetries for local and global processing reflect only asymmetric efficiencies with which local elements or global forms are processed. In the divided-attention task, in which the target level cannot be predicted, perhaps the RH directs attention to the preferred global level and the LH to the preferred local level during the entire task, in which case, RTs for one hemisphere would be delayed in switching from the preferred to target level and slower in processing the target than the opposite hemisphere once attention is switched.

In Experiment 1C, we investigated perceptual asymmetries in a two-choice task with divided attention. We found no evidence for a spatial-compatibility effect on this task (see the Appendix). However, the longer RTs on the two-choice task than the GNG divided-attention task indicate greater motor complexity for the former. As in the GNG tasks, the two-choice task yielded a reliable Level × Field interaction, an RH-LVF advantage for global perception, and an LH-RVF advantage for local perception. Although in the comparison of Experiment 1A (GNG) and 1C (two-choice) we could not detect modifying effects of response mode, stimulus type, or both together on the Level × Field interaction, both GS and ES letters in Experiment 1A but not 1C elicited reliable global and local asymmetries. In Experiment 1C (see the Appendix and Figure 5), reliable asymmetries were present only for the easier global (GS letters) and local (ES letters) tasks (see the Appendix). These observations suggest that when the perceptual task is difficult (global ES letters or local GS letters), simpler motor demands (GNG) reveal larger perceptual effects of hemispheric asymmetries than more complex motor demands (two-choice).

Finally, the examination of field asymmetries for single letters of different sizes revealed an LH-RVF advantage for the identification of medium single letters but no field asymmetry for large and small letters. Previous findings of LH-RVF advantages, RH-LVF advantages, or no asymmetries for single letters (e.g., Jonides, 1979) suggest that perceptual asymmetries for single letters reflect the influence of various unknown task factors (Christman, 1989). Our observation of an LH-RVF advantage only for medium letters, but not for large or small letters, indicates that the perceptual asymmetries in response to hierarchical stimuli cannot be explained by absolute stimulus size.

In summary, although planned comparisons in Study 1 suggest that perceptual asymmetries in response to hierarchical letters are more robust for ES stimuli, divided attention, and a GNG response, the effects of these variables were not reliable in main analyses. The Level × Field interaction was reliable in all three experiments for ES letters and on the divided-attention tasks but not in the focused-attention task for GS letters (see Figure 4 and the Appendix).

The lack of significant influence of attentional demands on the magnitude of perceptual asymmetries might reflect inadequate power to detect small differences between the tasks. In Study 2, we explore this possibility with a larger sample and a within-subjects design. The large sample size we use in Study 2 also allows highly accurate estimates of effect sizes and the minimum sample sizes necessary to detect perceptual asymmetries. Prior failures to find reliable Level × Field interactions might be due to insufficient sample sizes to detect small asymmetries.

Study 2

Our positive results in Study 1 stand in contrast to the failure of the majority of previous studies to detect perceptual asymmetries for global and local perception of lateralized hierarchical letters (e.g., Alivisatos & Wilding, 1982; Boles, 1984; Boles & Karner, 1996). All previous studies of manual responses to lateralized hierarchical letters presented GS stimuli and required a two-choice response (see Table 1). A majority of these studies also used a focused-attention task. None of the experiments in our Study 1 combined a two-choice response with a focused-attention task. The null results we observed in the focused-attention GNG task for GS letters (Experiment 1B) suggests that the focused-attention task may be less sensitive in detecting perceptual asymmetries for global and local perception, particularly with GS letters. In Study 2, we use a within-subjects design to compare two-choice responses to GS letters of a large sample of participants ($N = 59$) on focused- and divided-attention tasks. Not only does the two-choice task replicate the response demands of previous investigations, it allows us to use identical stimuli in the focused- and divided-attention tasks. The no-go stimuli in the GNG tasks (Experiments 1A & 1B) of Study 1 differed for the focused-attention task (a nontarget letter at the directed level but a target letter at the other level) and the divided-attention task (nontarget letters at both levels). Although go stimuli were the same in the two tasks, an anonymous reviewer noted that contextual effects of no-go trials could have influenced responses apart from the focused versus divided attentional demands. Thus, in Study 2 we compare divided and focused two-choice tasks, which include only stimuli with a target letter at one level and are identical in all aspects except attentional demands. Additionally, because the GNG divided-attention task of Study 1 elicited robust perceptual asymmetries, we further explore the effect of combining a GNG response with divided attention in Study 2, where participants responded only to GS letters.

Method

Participants

Fifty-nine right-handed undergraduate students at Northwestern University (30 men) participated in this study as part of their research participation requirement for an introduction to psychology course. Participants completed a 12-item handedness questionnaire on a 5-point scale (1 = *right hand always*, 2 = *right hand mostly*, 3 = *either hand equally*, 4 = *left hand mostly*, 5 = *left hand always*). Only participants who preferred the right hand (score of 1 or 2) on at least 11 out of 12 items and did not prefer the left hand on any item were recruited.

Stimuli

The hierarchical letters were similar to the GS stimuli used in Study 1 (see Figure 2) but were of a slightly different size. The global letter subtended 4.8° in height and 2.9° in width. The local letters subtended 0.45° in height and 0.38° in width. A similar poststimulus pattern mask consisting of two 9 column × 8 row matrices (each matrix, 3° in width and 3.9° in height) of small letters (0.15° × 0.1°) was presented simultaneously to the right and the left of a fixation cross. The medial edges of the two matrices were presented 0.5° lateral to the fixation point. The stimuli were generated and presented on a 15" monitor (640 × 480, 67Hz, Mac Std Gamma) of a Macintosh Performa 636CD by PsyScope software (Version 1.2, Cohen et al., 1993) and were viewed from a distance of 45 cm, which was controlled by a chin rest.

Procedure and Design

Participants were introduced to the experiment by signing a consent form in which they were given general information about the experiment. They then completed the handedness questionnaire. Each participant was tested on (a) a divided-attention GNG task that was identical to Experiment 1A (96 trials), (b) a divided-attention two-choice task that was identical to Experiment 1C (64 trials), and (c) a focused-attention two-choice task that was identical to the divided two-choice task in all factors except attentional instructions (96 trials). On the focused-attention task, participants were asked to focus only on the global level in one block of trials (48 trials) and only on the local level in another block of trials (48 trials). They were instructed to press one key when one of the targets was present at the designated level and the other key when the other target was present. The order of the three tasks as well as the order of the global and local blocks in the focused task was counterbalanced over participants. Each task commenced with 24 practice trials during which participants received an auditory feedback for their performance. No feedback was given during the task.

Data Analysis

RTs that were shorter than 250 ms or longer than 2,000 ms were excluded from the analyses. A repeated measures ANOVA with task (divided GNG, divided two-choice, focused two-choice), level (global, local), and visual field (LVF,RVF) as within-subjects factors and sex and task order (six combinations for the three tasks) as between-subjects factors was performed on correct RTs and their log transformations. Because the different tasks have different measures of accuracy, we analyzed error rates and their arcsine transformations for each task separately. Because analyses on transformed scores yielded the same outcomes as analyses on the raw scores, only the latter are described and depicted in figures.

Results

Reaction Times

Response speeds differed for the three tasks, $F(2, 94) = 78.20$, $p < .0001$. Latencies were longer on the divided two-choice than the divided GNG task, $F(1, 47) = 5.03$, $p < .03$, as in Study 1, and longer on the divided GNG than focused two-choice task, $F(1, 47) = 238.49$, $p < .0001$. The effect, however, differed for different task orders, as was confirmed by a significant interaction of task and task order, $F(10, 94) = 3.70$, $p < .0004$. For all six task orders, the fastest RTs occurred on the focused two-choice task. On the divided-attention tasks, GNG responses were faster than two-choice responses only for the two task orders in which the GNG task was last of the three tasks. There was no difference in RTs between the two divided tasks for the other four task orders. There were no other interactions with task order.

Faster RTs to the global than local level, $F(1, 47) = 37.02, p < .0001$, which did not interact with task, confirms the greater saliency of the global level on all tasks. The Level × Field interaction, $t(47) = 5.42, p < .0001$, one-tailed, confirmed an RH-LVF advantage for global decisions, $t(47) = 2.54, p < .008$, one-tailed, and an LH-RVF advantage for local decisions, $t(47) = -5.36, p < .0001$, one-tailed. However, there was a reliable difference among the three tasks in the magnitude of the Level × Field interaction, $F(2, 94) = 4.06, p < .02$, for the three-way interaction of task, level, and field. Although the Level × Field interaction was present for all tasks (Figure 6), Divided GNG, $t(47) = 4.37, p < .0001$, one-tailed, divided two-choice, $t(47) = 4.15, p < .0001$, one-tailed, focused two-choice, $t(47) = 2.94, p < .003$, one-tailed, the effect size was smaller on the focused two-choice (0.39) than on the divided two-choice (0.61) or divided GNG (0.59) tasks (Figure 7).

The Effect of Attentional Demands

A comparison confined to the two-choice tasks, which were identical in all task and stimulus factors except attentional demands (focused or divided), showed that perceptual asymmetries were influenced by the attentional demand. This finding was confirmed by a three-way interaction of task, field, and level, $F(1, 57) = 7.41, p < .009$. An RH-LVF advantage for global decisions was marginally significant on the divided-attention task, $t(47) = 1.45, p < .08$, one-tailed, but not significant on the focused-attention task, $t(47) = 0.17, p = .43$, one-tailed. Although an LH-RVF advantage for local decisions was present on both the focused, $t(47) = 3.75, p < .0001$, one-tailed, and divided, $t(47) = 4.34, p < .0001$, one-tailed, tasks, a Task × Field interaction for local RTs, $F(1, 57) = 6.71, p < .02$, revealed a larger asymmetry on the divided- than the focused-attention task.

The Effect of Response Demands

An analysis restricted to the two divided-attention tasks, which differed in response demands (GNG or two-choice), revealed a Level × Field interaction, $t(47) = 4.80, p < .0001$, that was not influenced by task, $F(1, 47) = 0.12, p = .73$. On the divided tasks, there was an RH-LVF advantage for global decisions, $t(47) = 2.12, p < .02$, one-tailed, and an LH-RVF advantage for local decisions, $t(47) = -3.21, p < .002$, one-tailed.

There was no main effect of sex nor any interactions of sex with other factors.

Error Rate

As in Experiment 1A, on the divided GNG task, the proportion of misses specified the error rate for each Field × Level condition because FAs cannot be assigned to one or the other level. An error on the two-choice tasks was a miss of the correct target letter as well as an FA for the other target letter. Thus, we analyzed accuracy levels for each experiment separately. Sex was a between-subject factor, and level and field were within-subject factors.

Divided GNG. A main effect of level, $F(1, 57) = 19.64, p < .0001$, indicated fewer misses of the global than the local level. An interaction of Level × Field, $t(57) = 2.08, p < .03$, one-tailed, reflects no field difference for the global level and fewer misses in the LH-RVF than the RH-LVF for the local level, $t(57) = 1.67, p = .05$, one-tailed. The FA rate was 5.5% in the RH-LVF and 6.6% in the LH-RVF.

Divided two-choice. A main effect of level, $F(1, 57) = 13.95, p < .0001$ indicated an overall global advantage. An interaction of level and field, $t(57) = 1.67, p = .05$, one-tailed, reflected no field difference for global decisions and an LH-RVF advantage for local decisions, $t(57) = 1.74, p < .05$, one-tailed.

Focused two-choice. As for the divided attention tasks, the focused attention task yielded an overall global advantage, $F(1, 57) = 6.17, p < .02$, but in contrast to the divided-attention tasks, the Level × Field interaction was not significant, $t(57) = 1.12, p = .13$, one-tailed.

Sample Size Analysis

Our analyses showed a significant Level × Field interaction for response latencies on all three tasks. This finding stands in contrast to the majority of previous studies, which used similar tasks (divided or focused attention, two-choice response, and GS letters) but failed to observe a significant Level × Field interaction. Although other task factors, such as eccentricity and the inclusion of a pattern mask in our task, might account for the discrepancy, failures to reject a null hypothesis can arise from inadequate power to detect small departures from zero. To assess this possibility, we determined the sample size that is necessary to reject the null hypothesis at $\alpha = .05$, two-tailed, given an effect size for the Level × Field interaction equal to our large sample observations. Figure 8 shows that on either of the divided-attention tasks (GNG or two-choice), the Level × Field interaction attains a conventional level of statistical significance with only 14 participants. However, at least 28 participants are required on the focused two-choice task to detect a Level × Field interaction.

Combined Analyses of Study 1 and Study 2

A combined analysis of responses to GS stimuli in Study 1 and observations from the initial task of participants in Study 2 was performed for the divided- and focused-attention tasks separately. Because we restricted data from Study 2 to observations from participant's initial task ($n = 17$ for initial divided GNG; $n = 22$ for initial divided two-choice; $n = 20$ for initial focused two-choice), the different tasks became group factors in Study 2, as in Study 1.

Divided-attention tasks. In the analysis of RTs to GS stimuli on the divided-attention tasks, study (Study 1, Study 2), sex, and mode of response (GNG, two-choice) were between-subjects factors, and level and field were within-subjects factors. RTs were faster on the GNG than on the two-choice task, $F(1, 62) = 17.84$ $p < .0001$. Global responses were faster than local responses, $F(1, 62) = 73.50, p < .0001$, but more so in Study 1 than in Study 2, $F(1, 62) = 5.06, p < .03$, for the Study × Level interaction. The Level × Field interaction was highly significant, $t(62) = 5.30, p < .0001$, one-tailed, and did not interact with any other factors. Global RTs were faster in the RH-LVF than the LH-RVF, $t(62) =$

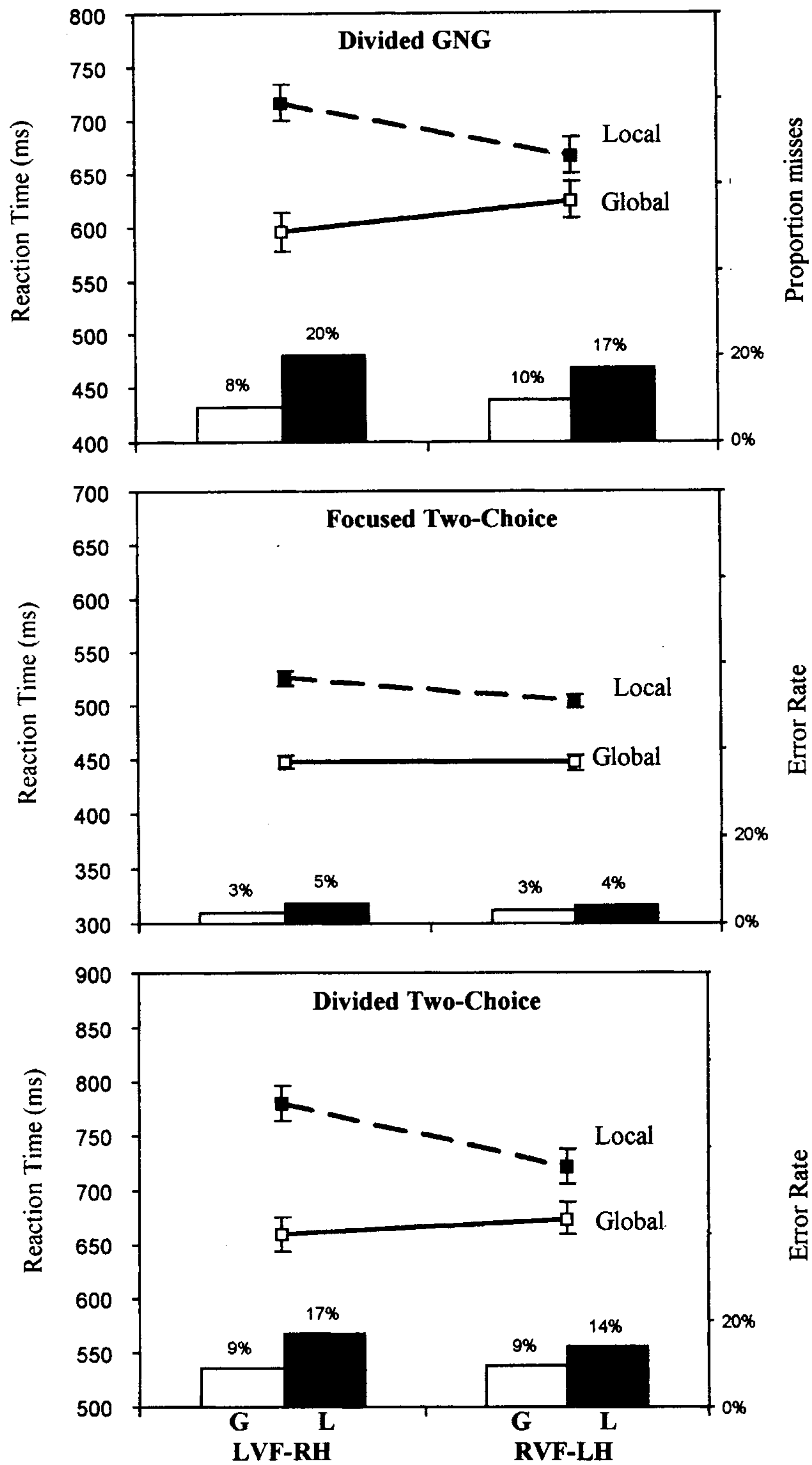

Figure 6. Mean reaction times (in milliseconds) and error rates for GS letters that were presented to the right hemisphere, left visual field (RH-LVF) and the left hemisphere, right visual field (LH-RVF) in the three experiments of Study 2. Error bars represent the standard error of the Level × Field interaction effect focused, Two-choice = 6.6; divided, Two-choice = 15.5; divided, GNG = 17.3. G = Global; L = Local. GNG = go/no-go.

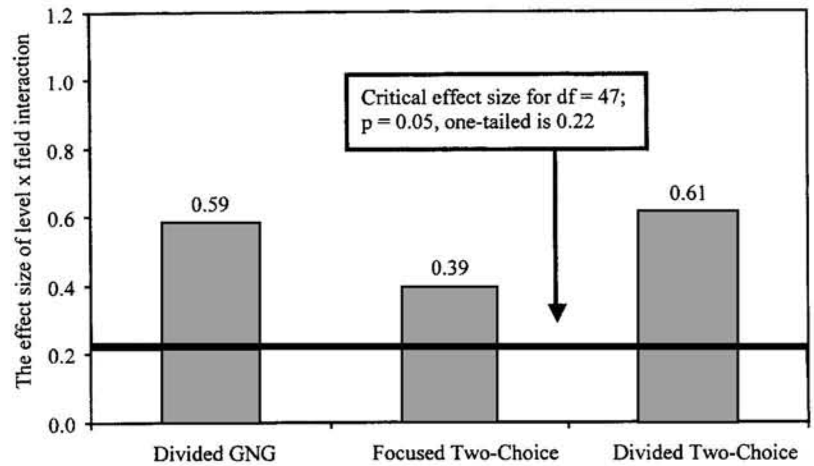

Figure 7. Effect sizes of the Level × Field interaction—[Local (LVF − RVF) − Global (LVF − RVF)]/ standard deviation of Level × Field interaction—of the three experiments of Study 2. The magnitude of the asymmetry effect is larger in the divided-attention tasks than in the focused-attention task. The critical effect size for $t(47)$, $p = .05$, one-tailed, is 0.26. LVF = left visual field; RVF = right visual field; GNG = go/no-go.

2.25, $p < .02$, one-tailed, and local RTs were faster in the LH-RVF than the RH-LVF, $t(62) = 4.61$, $p < .0001$, one-tailed. There was no main effect of sex nor any interactions with this factor.

Focused-attention tasks. Response (GNG in Study 1B; two-choice in Study 2) was the between-subjects factor, and level and field were the within-subjects factors in an analysis of RTs to GS stimuli on the focused-attention tasks. A main effect of response reflects faster responses on the two-choice task than on the GNG task, $F(1, 33) = 10.23$, $p < .003$, which was opposite to our findings on the divided-attention tasks. A main effect of level indicated faster responses to the global level, $F(1, 33) = 43.38$, $p < .0001$. The Level × Field interaction, $t(33) = 2.83$, $p < .004$, one-tailed, which did not interact with other factors, reflected an LH-RVF advantage for local perception $t(33) = 2.23$, $p < .02$, one-tailed, but no field asymmetry for global perception, $t(33) = 0.53$, $p = .30$.

Discussion

Study 2 revealed an RH-LVF advantage for global perception and an LH-RVF advantage for local perception for GS letters on the divided-attention tasks but only an LH-RVF advantage for local perception and no field difference for global perception on the focused-attention task (Figure 6). Further, the effect sizes of

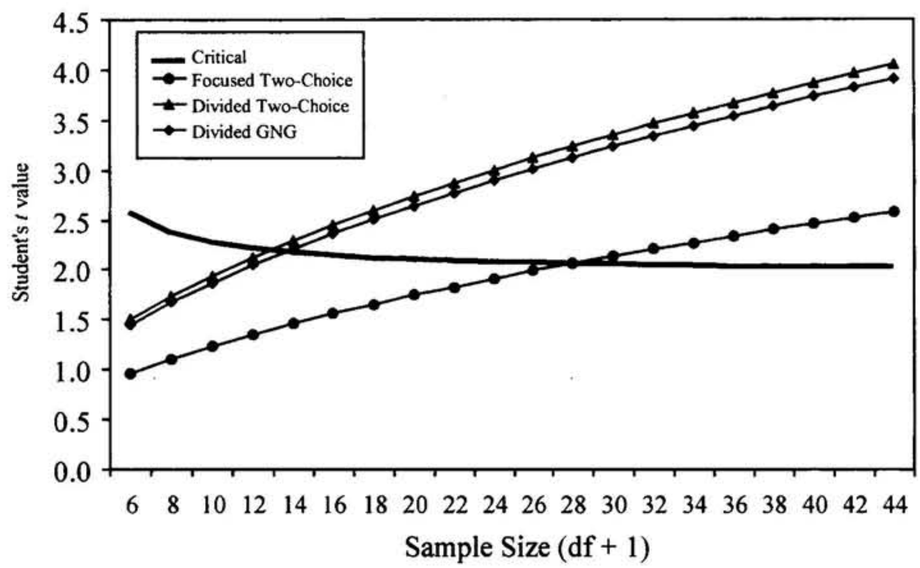

Figure 8. The sample size required to detect a significant Level × Field interaction ($p = .05$, two-tailed) given an effect size equal to the effects we observed in each of the three experiments in Study 2, which included 59 participants. GNG = go/no-go.

perceptual asymmetries for global and local perception were larger on the divided-attention tasks (two-choice and GNG) than the focused-attention task (Figure 7). These results support our observations in Study 1 of more robust asymmetries on the divided tasks (Experiments 1A & 1C) than on the focused task (Experiment 1B) for GS letters (see Figure 4) and are consistent with our hypothesis that a divided-attention task is more sensitive in revealing perceptual effects of hemispheric asymmetries.

Contrary to our prediction, the two-choice response did not result in reliably smaller perceptual asymmetries than the GNG response on the divided-attention tasks in either Study 1 or Study 2 (or both together) or on the focused-attention tasks (GNG in Study 1 compared with two-choice in Study 2). As indicated by response latencies, more complex motor programming was entailed by the two-choice response on divided-attention tasks, but by the GNG response on focused-attention tasks, in conflict with our suggestion that a two-choice response is essentially more complex than a GNG response. However, regardless of which response placed greater demands on motor programming, the motor demand had no influence on the perceptual effects of hemispheric asymmetries.

A sample size analysis reveals that to detect (with $\alpha = .05$, two-tailed) a Level × Field interaction in response to GS letters with the effect sizes we observed on the divided-attention tasks in Study 2 (GNG and two-choice), a sample size of $N = 14$ is sufficient, but for the smaller effect size on the less sensitive focused-attention task, a sample of $N = 28$ would be required (Figure 8). This analysis is consistent with our findings on the three experiments of Study 1, each with 16 participants, of reliable asymmetries for GS letters in the divided-attention tasks (Experiments 1A & 1C) but not the focused-attention task (Experiment 1B). It is also noteworthy that the Level × Field interaction on the focused task in Study 2 arose solely from an LH-RVF advantage for local decisions and no asymmetry for global decisions. Even with a sample size of 59 participants, we could not detect an RH-LVF superiority for global discrimination of GS letters on the focused-attention task (Figure 7).

General Discussion

Given the strong evidence for differences between hemispheres in local and global processing in neurological patients (e.g., Delis et al., 1986) and brain-imaging studies (e.g., Fink et al., 1997), the repeated failures to confirm these asymmetries in previous investigations of lateralized perception have puzzled researchers (Hellige, 1995; Ivry & Robertson, 1998; Van Kleeck, 1989). Our goals were to determine whether perceptual asymmetries for global and local processing would be reliably manifested when fixed-task factors were selected to maximize perceptual effects of hemispheric differences and, if so, how variable task factors of attentional demands, response requirements, and stimulus characteristics might influence these asymmetries. Overall, we found that perceptual asymmetries for global and local perception were larger on the divided- than the focused-attention tasks. Contrary to our predictions, the response mode did not reliably affect perceptual asymmetries on either the divided- or focused-attention tasks. The comparison of asymmetries for GS and ES letters in Study 1 revealed larger effect sizes for ES letters on all tasks (see Figure 4). The difference in the magnitude of perceptual asymmetries between ES and GS letters was not reliable on the divided-attention tasks. However, on the focused-attention task in Study 1 ($N = 16$), we observed local and global perceptual asymmetries for ES letters but neither asymmetry for GS letters. With a larger sample size in Study 2 ($N = 59$), the focused-attention task elicited an LH-RVF advantage for local perception of GS letters but no field difference for global perception (Figure 7).

Studies 1 and 2 both indicate more robust visual-field differences for global and local perception on the divided- than the focused-attention task. This finding is consistent with our hypothesis that unpredictable switches between the global and local levels from trial to trial enhance perceptual effects of hemispheric asymmetries. Two factors may underlie the observed field differences on a divided-attention task: (a) a delay for one hemisphere to switch attention from its preferred level to a nonpreferred target level (e.g., the RH has to switch attention from its preferred global level to a local target) and (b) slow processing of a target at the nonpreferred level once attention is switched (e.g., the RH processes a local target more slowly than does the LH). Only the last factor plays a role in perceptual asymmetries on the focused-attention task if participants attend to the directed level.

Planned comparisons indicated that the type of hierarchical letter influenced the pattern (Figure 5) and the magnitude (Figure 4) of perceptual asymmetries. Whereas GS letters attract attention to the global level in both visual fields, ES letters, which do not favor one level or the other, elicit faster local than global responses for the LH-RVF but not for the RH-LVF (Figure 5). More importantly, all three experiments in Study 1 show larger effect sizes for the Level × Field interaction when local and global levels are equally salient (ES) than for standard Navon-type hierarchical letters (GS, see Figure 4). These findings highlight the importance of stimulus characteristics for detecting perceptual differences between the two hemispheres and are consistent with the suggestion that equal salience of local and the global letters increases the sensitivity of stimuli to effects of hemispheric asymmetries on perception.

The small effect size of the Level × Field interaction for GS letters on the focused attention task and inadequate sample sizes to detect it may explain the failure to find reliable asymmetries in most previous experiments that used a focused task (Table 1). A sample-size analysis suggests that with a focused-attention task, at least 28 participants are required to detect perceptual asymmetries that are equal to those observed in Study 2. Of eight experiments that used a focused-attention task and failed to observe the expected asymmetries (see Table 1), including our Experiment 1B with GS letters, only one study included a sample size as large as 28 (Alivisatos & Wilding, 1982). Alivisatos and Wilding (1982) used a matching task, which may be less sensitive in revealing perceptual effects of hemispheric asymmetries than the commonly used identification task.

In addition to sample size, other task factors, such as backward masking and eccentricity, which distinguish our studies from the majority of previous reports (see Table 1), may be important in obtaining significant asymmetries for global and local perception. Such factors may account for the discrepancy in our findings on the divided-attention task and previous investigations that presented a similar attentional task. Of five previous experiments that used a divided-attention task, only Sergent (1982) reported a significant interaction of level (global, local) with visual hemifield.

Sergent's stimuli were displayed only 0.75° lateral to fixation, which differentiates her study from the larger eccentricities used in other published studies. Our stimuli were presented 0.5° lateral to fixation. Small eccentricity may also explain the positive findings of Martin (1979) and Hubner (1997), who used a focused-attention task and presented hierarchical letters adjacent to the vertical meridian. It may be that larger perceptual asymmetries are correlated with smaller eccentricities of lateralized stimuli. The influence of eccentricity, however, cannot account for the positive findings of Robertson et al. (1993) on their focused-attention task and the negative findings of Boles (1984; Boles & Karner, 1996), who used a smaller eccentricity (see Table 1), on his focused-attention task, which highlights the multiplicity of factors that can influence perceptual asymmetries in response to lateralized hierarchical letters.

Van Kleeck (1989) suggested that practice effect or fatigue might account for the repeated failures to reveal perceptual asymmetries for global and local perception in previous reports. Our studies presented 256 trials, which is more than the number of trials in most previous reports of negative findings (see Table 1), and revealed no evidence for practice effects. Moreover, Hubner (1997), who presented 2,880 trials, found reliable visual-field differences.

The reliable perceptual asymmetries on the variety of tasks in our studies, as well as the positive and negative results of previous investigations, suggest that there is no single task factor that is critical for revealing or concealing perceptual effects of hemispheric asymmetries. Rather, the probability of observing reliable asymmetries in favor of the RH-LVF for global perception and the LH-RVF for local perception depends on various combinations of multiple task factors (e.g., ES letters, divided attention, backward masking, small eccentricity). Our studies show that divided-attention tasks with either GS or ES letters and focused-attention tasks with ES letters produce perceptual asymmetries that favor the RH for global perception and the LH for local perception. However, for standard Navon-type letters (GS letters), the focused-attention task yields only an LH advantage in local perception but no asymmetries for global perception.[1] As discussed in our introductory section, perceptual differences between hemispheres will be reduced or absent if a task is so easy that both hemispheres are near ceiling. We suggest that ceiling effects on our focused-attention tasks account for the absence of reliable perceptual asymmetries for global discrimination of GS letters.

In conclusion, we have established that differences between the two hemispheres in global and local processing, which are consistent with neurological and physiological findings, can be reliably revealed in lateralized tachistoscopic studies of healthy individuals. We introduce several task factors that are sensitive in detecting these differences (divided attention, ES letters) and therefore should be considered in future investigations of hemispheric asymmetry for global and local perception.

[1] Sample size analysis shows that at least 28 participants are required to reveal departure from local symmetry for GS letters in a focused-attention task.

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Appendix

Individual RT ANOVAs for Experiments 1A, 1B, and 1C

Experiment 1A—Divided GNG

A robust Level × Field interaction $t(12) = 5.59$, $p < .0001$, one-tailed, reflects an RH-LVF advantage for global RTs, $t(12) = 3.36$, $p < .003$, one-tailed, and an LH-RVF advantage for local RTs $t(12) = -3.34$, $p < .003$, one-tailed.

The Type × Level × Field interaction was not significant, $F(1, 12) = 3.41$, $p = .09$. The Level × Field interaction was significant both for ES letters, $t(12) = 4.51$, $p < .001$, one-tailed, and GS letters, $t(12) = 3.34$, $p < .003$, one-tailed (see Figure 5). The global RH-LVF advantage was significant for ES decisions, $t(12) = 2.81$, $p < .008$, one-tailed, and marginally significant for GS decisions, $t(12) = 1.65$, $p < .07$, one-tailed. The local LH-RVF advantage was significant for both ES, $t(12) = -2.94$, $p < .01$, one-tailed, and GS, $t(12) = -2.74$, $p < .01$, one-tailed, stimuli. Comparisons within visual fields showed that for GS letters, global responses were faster than local responses in both the LH-RVF $t(12) = 5.55$, $p < .0001$, and RH-LVF, $t(12) = 7.29$, $p < .0001$, whereas for ES letters, global responses were faster than local responses in RH-LVF, $t(12) = 2.54$, $p < .03$, but local responses were faster than global response in the LH-RVF, $t(12) = -1.75$, $p = .1$.

The only other significant finding was a three-way interaction of Level × Field × Sex, $F(1, 12) = 12.56$, $p < .005$, which reflects a larger Level × Field interaction in women, $t(6) = 5.18$, $p < .002$, one-tailed, than in men, $t(6) = 2.16$, $p < .04$, one-tailed. The reliability of this interaction is open to serious question because the effect is neither conceptually nor empirically predicted.

Experiment 1B—Focused GNG

A Level × Field interaction, $t(12) = 4.61$, $p < .0005$, one-tailed, indicates faster RTs to the global level for the RH-LVF than LH-RVF, $t(12) = 1.85$, $p < .05$, one-tailed, and faster RTs to the local level for the LH-RVF than RH-LVF, $t(12) = -2.84$, $p < .008$, one-tailed. Although the absence of a three-way interaction of type, level, and field, $F(1, 12) = 1.23$, $p = .29$, gives no evidence that ES stimuli elicit larger perceptual asymmetries than GS stimuli, the Level × Field interaction was significant for ES stimuli, $t(12) = 2.90$, $p < .01$, one-tailed, but not for GS stimuli, $t(12) = 1.29$, $p = .11$, one-tailed. Because the probability of a Type I error in the overall Level × Field interaction for ES stimuli is very low, the inferential inconsistency almost certainly reflects a Type II error in the three-way interaction in the general analysis, the two-way Level × Field interaction for GS stimuli, or both. We think it is likely that a Level × Field interaction obtains for both stimulus types (Type II error for GS letters) and is larger for ES than GS letters (Type II error for the three-way interaction).

For ES stimuli, both the RH-LVF advantage for global decisions, $t(12) = 1.93$, $p < .04$, one-tailed, and the LH-RVF advantage for local decisions, $t(12) = -2.73$, $p < .01$, one-tailed, were significant, but for GS stimuli, neither global nor local RTs differed significantly between fields. Comparisons within visual fields showed that for ES letters, local and global RTs were equal in the RH-LVF, whereas local responses were faster than global responses in the LH-RVF, $t(12) = -3.89$, $p < .001$. For GS letters, there were faster RTs to the global than local level in LH-RVF, $t(12) = 3.81$, $p < .002$, and RH-LVF, $t(12) = 5.12$, $p < .0001$. In contrast to Experiment 1A, in which we found a larger Level × Field interaction for women than men, there was no influence of sex on the Level × Field interaction in Experiment 1B, $F(1, 12) = 0.18$, $p = .68$.

Experiment 1C—Divided Two-Choice

A repeated measures ANOVA was performed on RTs, in which type of stimulus (ES, GS), visual field (RVF, LVF), and level (local, global) were within-subject factors and sex, response hand, and key location (left, right) were between-subject factors. The key location factor was added to the analysis to determine whether two-choice RTs were contaminated by effects of spatial compatibility. If responses are faster to the left key for the LVF and faster to the right key for the RVF, this would emerge as a Field × Key Location interaction. There was no trend toward a significant interaction, $F(1, 12) = 0.10$, $p = .76$, which shows that spatial compatibility did not influence RTs in our experiment. Because no main effect of key or any interactions with this factor were found, it was omitted from the final analysis.

The Level × Field interaction, $t(12) = 3.17$, $p < .003$, one-tailed, indicated faster RTs to the global level for the RH-LVF than the LH-RVF, $t(12) = 3.01$, $p < .006$, one-tailed, and faster RTs to the local level for LH-RVF than the RH-LVF, $t(12) = -2.01$, $p < .03$, one-tailed. The Level × Field interaction was not influenced by stimulus type (GS, ES), as shown by a null three-way interaction, $t(12) = 0.43$, $p = .34$, and was significant both for ES, $t(12) = 2.92$, $p < .001$, one-tailed, and GS $t(12) = 2.03$, $p < .04$, one-tailed, stimuli. Although the significance of the Level × Field interaction was greater for ES than GS letters, planned comparisons showed an RH-LVF advantage for global GS letters, $t(12) = 2.64$, $p < .008$, one-tailed, but not for global ES letters, $t(12) = 0.89$, $p = .20$, one-tailed, in contrast to observations in Experiments 1A and 1B and our expectation that asymmetries would be more pronounced for ES than GS letters. However, the LH-RVF advantage for local decisions was significant for ES, $t(12) = -2.90$, $p < .004$, one-tailed, but not for GS, $t(12) = 1.43$, $p = .09$, letters. Local and global RTs for ES letters did not differ within either visual field, whereas global responses were faster than local responses for GS letters in both the LH-RVF, $t(12) = 2.96$, $p < .004$, and RH-LVF, $t(12) = 6.97$, $p < .0001$. As in Experiment 1B, there was no significant influence of sex on the Level × Field interaction.

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