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Organizational and Spatial Dynamics of Attentional Focusing in Hierarchically Structured Objects

Menahem Yeari and Morris Goldsmith
University of Haifa

Is the focusing of visual attention object-based, space-based, both, or neither? Attentional focusing latencies in hierarchically structured compound-letter objects were examined, orthogonally manipulating global size (larger vs. smaller) and organizational complexity (two-level structure vs. three-level structure). In a dynamic focusing task, participants successively identified the global and local letters in the same trial. Overall response latencies were generally longer for larger versus smaller global objects and for three-level versus two-level object structure, indicating that attentional focusing time increases both with the magnitude of change in attentional aperture size and with the number of traversed levels of object structure. Additional experiments showed that this pattern is unique to tasks that require dynamic attentional focusing. Taken together, the results support a hierarchical object-based-spatial model of attentional focusing.

Keywords: visual attention, focusing, object-based vs. space-based, hierarchical organization, global-local

Several decades of intensive research have spawned various theories and models of visual attention, each emphasizing different aspects of its postulated operation. Early models used various spatial metaphors, such as spotlights (e.g. Eriksen & Eriksen, 1974; Posner, 1980), zoom lenses (e.g. Eriksen & St. James, 1986; Eriksen & Yeh, 1985), and gradients (e.g., Downing & Pinker, 1985; LaBerge & Brown, 1989), to characterize the manner in which attention is allocated. Despite their differences, these metaphors all share a common central assumption—that attention operates in a spatial manner on a purely spatial representation of the visual field—a notion that is generally referred to as the *space-based* view of visual attention. An alternative view emphasizes the influence of perceptual organization on attentional selection. According to this *object-based* view (e.g., Duncan, 1984; Kahneman & Henik, 1981; Kramer & Jacobson, 1991; see Scholl, 2001 for a review), attention does not simply select unparsed and unorganized regions of space; rather, the basic units of selection are perceptual groups or objects that emerge from the pre-attentive segmentation and organization of the visual field, based on Gestalt grouping principles (Wertheimer, 1923) and uniform connectedness (Palmer & Rock, 1994).

Work in the past two decades has shown that the object-based and space-based views of attention are not mutually exclusive, and may in fact complement one another (e.g., Egly, Driver, & Rafal, 1994; Vecera & Farah, 1994), leading many to adopt a more integrated view, in which attentional selection has both space-based and object-based components (e.g., Arrington, Carr, Mayer, & Rao, 2000; Goldsmith, 1998; Goldsmith & Yeari, 2003; Humphreys & Riddoch, 1993; Logan, 1996). According to this view, attention operates on a spatial representation that includes object boundaries and perhaps other types of organizational structure. Exemplifying this approach, Vecera (1994) and Arrington et al. (2000) have proposed the terms *grouped-spatial-array* and *object-based spatial* attention, respectively, to capture the idea that perceptual objects define organized regions of space that may be selected for attentional processing.

Most of the work on object-based versus space-based attention has centered on the nature of the *unit of selection*—perceptual objects or unparsed regions of space. There has been much less work addressing the different implications of the two conceptions regarding the *dynamics* of attention, in particular, the manner in which attention is shifted from one selected unit to another. Two types of attentional shifts are generally distinguished: *orienting* (also referred to as *movement*) and *focusing* (also referred to as *zooming*; e.g., Castiello & Umiltà, 1990; Egly & Homa, 1991; Shepherd & Müller, 1989; Stoffer, 1993; Stoffer & Umiltà, 1997; Wright & Ward, 1994). Usually conceived of and examined in space-based terms, orienting-movement refers to the process of shifting the focus of attention from one location (or perceptual object) to another, without changing its spatial scale (without changing the diameter of the attentional "spotlight"), whereas focusing-zooming refers to a change in the size or scale of the region (or perceptual object) that is selected. Although different

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Menahem Yeari and Morris Goldsmith, Department of Psychology, University of Haifa.

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Correspondence concerning this article should be addressed to Menahem Yeari or Morris Goldsmith, Department of Psychology, University of Haifa, Haifa, 31905, Israel. E-mail: myeari@gmail.com or mgold@research.haifa.ac.il

models of attentional shifts—as well as selection—are implied by the object-based and space-based views, these differences have generally been left implicit, and have not been subjected to direct empirical tests (for notable exceptions, see Brown & Denny, 2007; Shomstein & Yantis, 2002, 2004).

In the present research, we address the nature of attentional focusing, with specific regard to its space-based and object-based dynamics. Unlike the dynamics of attentional movement, which have been examined extensively within the space-based framework, both with regard to the notion of "engagement/disengagement" (e.g. Posner & Cohen, 1984; Posner & Petersen, 1990; Posner, Petersen, Fox, & Raichle, 1988) and to the issue of whether the movement is analog or discrete (see review by Egly & Homa, 1991), the dynamics of attentional focusing have been largely neglected in both the space-based and the object-based research frameworks.

Rationale and Overview of the Present Research

The notion of attentional focusing is perhaps most strongly associated with the spatial, "zoom lens" metaphor (Eriksen & St. James, 1986; Eriksen & Yeh, 1985), by which the size of the attended region is dynamically adjusted according to task demands. Assuming that a fixed amount of attentional resources are distributed equally across the attended region, an inverse relationship is expected between the size of the attentional focus and processing efficiency of stimuli falling within that focus. A great deal of research supports this general prediction (e.g., Eriksen & St. James, 1986; LaBerge, 1983; Müller & Findlay, 1988; Henderson, 1991), while also suggesting some modifications (e.g., Downing & Pinker, 1985; LaBerge & Brown, 1986, 1989). Little research, however, has been devoted to the *manner* in which attention is focused (see General Discussion). Is attentional focusing a spatial-analog process, as implied by the zoom lens metaphor? If so, one clear implication is that focusing time should be a positive function of the magnitude of the change in size of the attended region (cf. Egly & Homa, 1991; Tsal, 1983). As far as we know, this simple prediction has, until now, evaded empirical examination.[1]

Nor is it known whether the process of attentional focusing, and hence the time needed to perform this focusing, is constrained or influenced by object-based factors, such as the perceptual organization and structure of the visual field. Much of our visual world has a gross hierarchical structure (Marr, 1982; Navon, 1977; Palmer, 1977; Treisman, 1986), for example: house-wall-window-pane, body-head-face-nose, piano-keyboard-key, table-platter-plate-food, and so forth. Thus, one may sometimes first attend to an entire table top and then focus one's attention on a piece of cake that is on one of several plates that are on one of several platters on that table top. How does one do so? In shifting one's attention from the table to the cake, must one necessarily attend to the intervening levels of hierarchical structure (e.g., platter and then plate), or can attention simply "jump" directly from the table to the cake? If there are organizational constraints on attentional focusing, might these coexist with spatial constraints? For example, would it take less time to focus on the cake if attention had initially been spread across a smaller table top? To guide our examination of such questions, four alternative models of attentional focusing were derived and compared (see Figure 1).

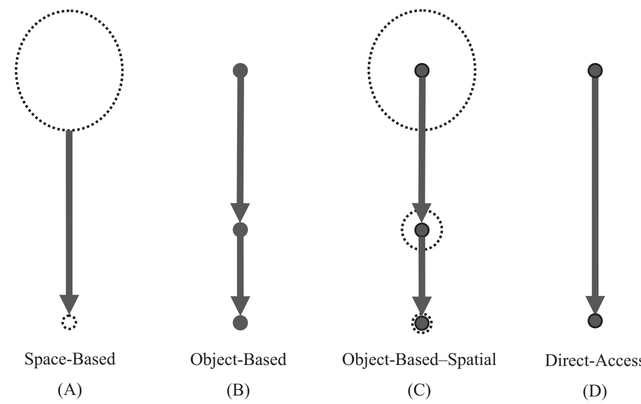

Figure 1. Schematic depiction of attentional focusing in a multi-level, hierarchically structured visual stimulus, according to four alternative models: (a) pure space-based, (b) pure object-based, (c) object-based-spatial, and (d) direct-access. Open circles (attentional apertures) of different sizes represent spatial constraints on focusing; intervening solid circles (perceptual objects) represent structural-organizational constraints on focusing (see text for further explanation).

According to the *pure space-based model* (Figure 1A), attentional focusing is performed in an analog manner within a spatial medium, sensitive only to spatial aspects such as the change in size of the attentional "aperture." In particular, the time needed to change the attentional aperture from one setting (size) to another should be a positive function of the magnitude of the change. Continuing with the table-cake example, it should take longer to focus on a piece of cake if one had initially been attending to a large rather than small table. Similarly, it should take longer to de-focus attention from the cake back to a larger table than to a smaller table. The presence or absence of intermediate-level plates or platters would be of no relevance.

According to the *pure object-based model* (Figure 1B), attentional focusing is performed discretely in an organized, hierarchically structured medium, sensitive only to organizational-hierarchical object structure. In particular, the time taken to change the attentional focus from one hierarchical level to another should be a positive function of the number of intervening levels of object structure (perceptual objects or "parts") that must be traversed. Thus, for example, in focusing one's attention from the table to a piece of cake, attention would be constrained to shift from the table

[1] A study by Benso, Turatto, Mascetti, and Umiltà (1998) may provide some tentative evidence supporting this prediction. In their study, a small dot presented as an exogenous precue was followed by a surrounding circular cue that could be either large or small, with cue-target SOA ranging from 33 ms to 704 ms. For SOAs between 66 ms and 469 ms, target detection was significantly faster with the smaller than the larger circular cue, indicating that attention had been differentially focused. The nonsignificant difference at SOA = 33 ms was taken to reflect the lack of sufficient time to initiate and adapt the attentional focus to the size of the cue. Although Benso et al. did not interpret their results this way, another possibility is that 33 ms was sufficient to "zoom out" from the initial dot cue to the region encompassed by the small circular cue (regardless of which cue had in fact been presented, yielding equivalent target-detection performance), but that more time—up to 66 ms—would be needed to reach the size of the larger circular cue.

to the platter, from the platter to the plate, and finally from the plate to the cake. Each intervening node on the hierarchical object-based route would incur an additional "access cost" because of the need to open its "object file" (Kahneman & Treisman, 1984) or to perform an "engage/disengage" operation (Brown & Denny, 2007) on its perceptual-object representation. Importantly, by this pure object-based model, focusing time should be completely independent of differences in the sizes of the objects that are sequentially attended.

Combining the preceding two models, the *object-based-spatial model* (Figure 1C) holds that attentional focusing is performed on a representation that is both spatially and perceptually (hierarchically) organized, including both space-based (e.g., size, distance, spatial relations) and object-based (e.g., perceptual object boundaries, grouping strengths, hierarchical structure) information. Critically, by this model, attentional focusing (or de-focusing) should be sensitive to both spatial and organizational parameters. Thus, as in the pure object-based model, attentional focusing is constrained to follow a hierarchical object-based route from one hierarchical level to another, attending to intervening nodes (objects or parts) if present, each incurring an additional access cost. In addition, however, the focusing operation per se is spatial-analog, and hence the time taken to change the attentional focus from, say, the table to the cake or vice versa, will be a function of *both* the number of intervening hierarchical levels (e.g., platter or plate), *and* the magnitude of the required change in the size of the attentional aperture (e.g., the size difference between the table and the cake).

Finally, according to the *direct-access model*, attentional focusing is performed discretely, and is sensitive neither to spatial nor to organizational parameters. Illustrated in terms of our table-plate-cake example, this model holds that attention can shift directly from the table representation (or its spatial region) to the cake representation (or its spatial region), without any regard for the number of intervening levels of organization (platters or plates) and without any regard for the spatial size difference between the table and the cake. The direct-access model is considered here to be the "default" model, which should be assumed barring evidence to the contrary (i.e., evidence that focusing is spatially or organizationally constrained). In this sense, as a model of attentional focusing, it plays a role similar to the so-called "discrete" models that have been proposed and examined in opposition to "spatial-analog" models of attentional orienting (e.g., Chastain, 1992; Cheal and Lyon, 1989; Remington and Pierce, 1984; Sperling & Weichselgartner, 1995; see Egly & Homa, 1991, for a review).[2]

The predictions of these four models were compared in a series of experiments using a special *dynamic hierarchical focusing* paradigm developed for this purpose. The visual stimuli were hierarchically structured compound letters similar to those used extensively in the context of the "global-local" research paradigm (e.g., Kimchi, 1992; Navon 1977). However, unlike the common procedure in that paradigm, in which the target is identified at either the global *or* the local level on each individual trial, in this new paradigm the participants were required to identify *first* the global letter ("*H*" or "*S*") and *then* the local letters (*H* or *S*), or vice versa, *successively in a single trial*. Spatial and organizational aspects of the stimuli were orthogonally manipulated (see Figure 2): (1) *size of the global letter*—large versus small (with local-letter size held constant); and (2) *organizational complexity* (number of hierarchical levels)—two-level structure, in which a global letter is composed entirely of local letters (the "standard" compound-letter stimuli used in global-local research); versus three-level structure, in which a global letter is composed of intermediate-level rectangles, which are themselves composed of local letters. The main dependent variable was *overall* response time (RT): beginning with the offset of the neutral compound fixation stimulus (a global "8" digit composed of local "8" digits) into the target stimulus, and ending with the second target identification key press. This measure is assumed to reflect the time needed to identify the global letter, focus attention to the local level, and then identify the local letters, or vice versa (depending on task instructions). Further assuming that the perceptual discriminability of the global and local letters is equivalent for all combinations of global size and organizational complexity (based on pretesting; see Appendix I), any differences in overall RT between

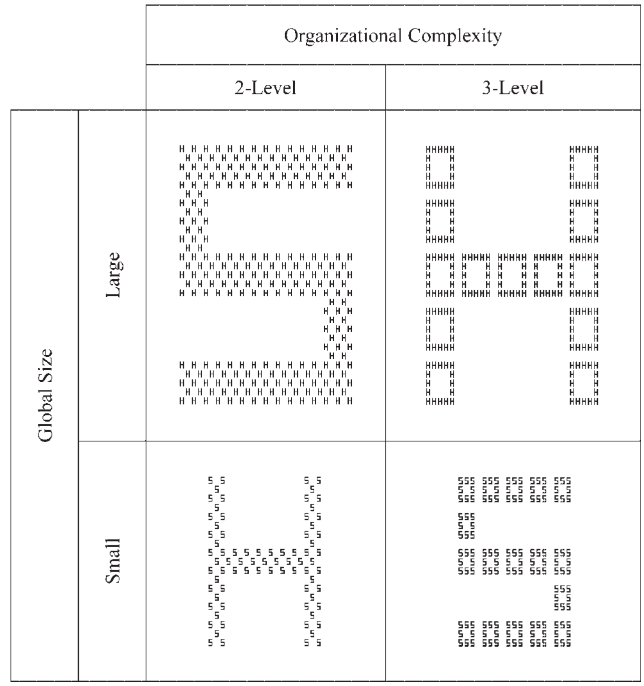

Figure 2. Four examples of hierarchical compound-letter stimuli: 2 sizes of global letter (large vs. small) × 2 levels of organizational complexity (two-level vs. three-level).

[2] Discrete models of attentional orienting (i.e., movement—not focusing) hold that attentional shifts are executed as discrete quantized jumps (e.g., Remington and Pierce, 1984; Sperling & Weichselgartner, 1995). Sperling & Weichselgartner (1995), for example, suggested that attentional shifts might be likened to the turning on or off of different attentional "spotlights" centered at fixed spatial locations across the visual field. As such, the time needed to switch from one spotlight to another should be insensitive to the distance between the spotlights' locations, and to the presence or absence of intervening stimuli. In contrast, spatial-analog models imply that (a) the time needed to move attention between two locations should be a positive function of the distance between the two points, and (b) shifting attention between two locations requires that attention move though all intervening locations. The findings in this regard have been inconclusive (see Egly & Homa, 1991 for a review).

these conditions can only be attributed to the effect of the manipulated variables (spatial and organizational variables, respectively) on the time needed to focus attention between the global and local levels.

Each of the attentional-focusing models outlined above predicts a unique pattern of effects on focusing time, and consequently on overall RT: (1) The *pure space-based model* predicts that overall RT will be longer for the larger than for the smaller global stimuli, because of the greater global-local size difference requiring a greater focal change, with no effect of organizational complexity; (2) The *pure object-based model* predicts that overall RT will be longer for the three-level than for the two-level stimuli, because of the additional intervening level of object structure that must be traversed (additional access cost), with no effect of global size; (3) Combining the preceding two predictions, the *object-based-spatial model* predicts that overall RT will be affected by both global size and organizational complexity; (4) The *direct-access model* predicts that neither global size nor organizational complexity will affect overall RT.

Experiment 1 constituted the basic test of the four models, using the stimuli and paradigm just described. To anticipate, this experiment yielded evidence of both spatial and organizational effects on attentional focusing, thereby supporting the object-based-spatial model. Two subsequent experiments provided converging evidence that the influence of organizational complexity is tied specifically to hierarchical attentional focusing: Experiment 2 manipulated the nature of the task— identification versus detection —showing that organizational complexity affects overall RT in an identification task, in which attention must be focused dynamically to a particular element at the local level, but not in a detection task, which can be accomplished with attention spread across the global object. Experiment 3 showed that when the local target letter was not part of the hierarchical object structure, but rather was a detached element encompassed by the global letter, the effect of organizational complexity on overall RT was largely eliminated.

Experiment 1

Experiment 1 examined the central issue regarding the nature of attentional focusing: Is it purely spatial, purely object-based, object-based-spatial, or performed by direct access? As just described, the experiment used the dynamic hierarchical focusing task on compound-letter stimuli, manipulating both global size (large or small) and organizational complexity (number of structural levels: two or three). The direction of the required attentional shift, from global to local (focusing), or from local to global (defocusing), was manipulated between blocks, whereas global size and organizational complexity were manipulated within blocks. Each trial began with the presentation of a neutral compound fixation stimulus—a global LED-style 8 digit composed of local LED-style 8 digits, having the same global size as the experimental stimulus for that trial (see Figure 3). This allowed the participants to fixate their attention initially at the appropriate level of object structure (global, in global-to-local trials, or local, in local-to-global trials), while temporarily concealing both the identities of the global and local letters and the structural organization (two-level or three-level). After one second, the fixation stimulus was offset smoothly (over a 30-ms interval) into the experimental compound-letter stimulus at both the global and local levels (H or S), by removing the appropriate local 8 digits and the appropriate pixels within each remaining local 8 digit, respectively. The participants were then required to respond as quickly as possible to the identity of the letter at each level, in the required order, by making the appropriate key presses.

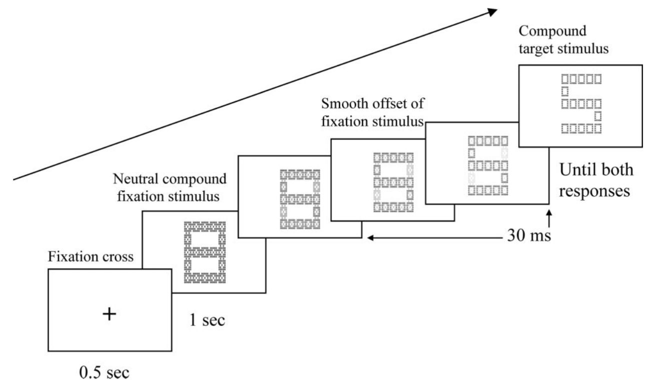

Figure 3. The sequence of events in a trial of Experiment 1.

Several aspects of the procedure were designed to ensure that the participants would attend first to the stimulus at the initial level, identify the letter at that level, and then dynamically shift the attentional focus to the other hierarchical level, in the specified order (rather than dividing attention, or shifting attention in the opposite order):

(1) The instructions emphasized that the participants should follow this sequence.

(2) Participants were instructed to fixate their attention in advance on the first level to be identified, and the 1-s presentation of the compound fixation stimulus, with a smooth offset of this stimulus into the experimental stimulus (by fading out irrelevant pixels), was designed to facilitate this.

(3) The global letters were at least 35 times larger than the local letter elements, making the identification of the local letters very difficult without focused attention.

(4) On half of the trials, the identities of the letters at the global and local levels were incongruent, so that even if the local letters could be identified with attention spread across the global letter, sequential focused attention should reduce global-local interference compared to a divided-attention strategy.[3]

(5) An incorrect first response caused immediate termination of the trial (with feedback).

The predictions of each of the four models with regard to the effects of global size and organizational complexity on the overall response time needed to make both identifications, were specified in the earlier overview section, and can be summarized as follows: An effect of global size only would support the pure space-based model and count against the other three models; an effect of

[3] Note that the identities of the global and local letters could be either congruent (global H and local H; global S and local S) or incongruent (global H and local S; global S and local H), with this factor fully crossed with the global-size and organizational-complexity variables. Global-local congruency effects, which are of primary interest in research within the standard global-local paradigm (to examine global/local dominance; see Kimchi, 1992), are of no direct interest in the present research.

organizational complexity only would support the pure object-based model and count against the other three models; effects of both global size and organizational complexity would support the object-based-spatial model and count against the other three models. Null results with regard to both manipulations would support the direct-access model and count against the other three models.

Method

Participants

Sixteen undergraduate students at the University of Haifa participated in the experiment for payment (NIS 35) or course credit, for a 45-min session. All participants had normal or corrected-to-normal vision.

Apparatus and Stimuli

The experiment was run on an IBM PC compatible computer and a Super VGA, high-resolution color monitor. The stimuli were black on a light background. The fixation cross subtended 1.1° × 1.1°. The hierarchical stimuli were formed from many *local* stimulus letters arranged into a *global* stimulus letter. All stimulus letters (local and global) were composed solely from straight "lines" (collinear pixels for the local letters; collinear elements for the global letters), and were approximately 1.5 times as tall as they were wide. Each local letter subtended 0.15° × 0.23°, and was used to compose two sizes of global letters: The large global letters subtended 8.5° × 13°, with a line width of five local elements, and the small global letters subtended 5.7° × 8.5°, with a line width of three local elements. *Two-level* compound letters were composed of local letters filling alternating element positions (filled-empty-filled-empty . . .) within the matrix. *Three-level* compound letters were formed by configuring the local letters contiguously into rectangle shapes, with single-element spacing between the rectangles to form the global letters.

The global and local letters were uppercase *H* or *S*, including all four combinations of global and local letter identity, fully crossed with the other manipulated variables. The two-level patterns were composed of 193, 253, 77, and 101 local letters, which composed the large-*H*, large-*S*, small-*H* and small-*S* global letters, respectively. The three-level patterns were composed of 208 and 104 local letters, which composed 13 intermediate-level rectangles, composing the large-*H* and small-*H* global letters, respectively, and 272 and 136 local letters, which composed of 17 intermediate-level rectangles, composing the large-*S* and small-*S* global letters, respectively. The rectangles of the large pattern subtended 1.4° × 2.2°, with a line width of one local element, and the rectangles of the small pattern subtended 0.8° × 1.1°, with a line width of one local element. The perceptual discriminability of the global and local letters of these stimuli were equated on the basis of pretesting (see Appendix I).

Sixteen different *compound target stimuli* were formed by orthogonally combining 2 global sizes × 2 levels of organizational complexity × 4 combinations of global and local letter shapes. Two additional *compound fixation stimuli* were formed by composing a large or small global LED-style 8 digit from a matrix of either 305 or 133 local elements, respectively, which were also LED-style 8's. The local elements of these stimuli were placed in all positions that were common to the eight compound target stimuli of the same global size, so that both the letter identities and the organizational complexity of the subsequent target stimulus would not be revealed.

In addition, a special *response-mapping practice* block used "normal" (not compound) *H* and *S* letters in three different sizes, equal in overall size and line width to the local, small-global, and large-global letters of the compound stimuli.

Procedure

Participants were tested individually. Each participant sat in a dimly lit room at a distance of about 50 cm from the computer screen, with head stabilized by a chin rest. All instructions were presented on screen. Any questions were answered by the experimenter.

The experiment began with a *response-mapping practice* block of 60 trials, designed to achieve a fluent and relatively automatic mapping between each target letter and its associated response key, before beginning the experimental phase. Each response-mapping trial began with a blank screen for 1 s, followed by a fixation cross appearing at the center of the screen for 0.5 s. A normal (not compound) letter, *H* or *S,* in one of three sizes then appeared until the participant responded (or until 2 s had passed). The participants' task was to indicate by a key press the identity of the letter.

The response-mapping block was followed by four *experimental* blocks of 160 trials each. In two consecutive experimental blocks, participants responded initially to the global letter and then to the local letter, while in the other two blocks they responded in the opposite order, with the order of these pairs of blocks counterbalanced across participants. A block of 48 *experimental practice* trials preceded each pair of experimental blocks.

Each *experimental* trial (and their identical *practice* trials; see Figure 3) began with a blank screen for 1 s, followed by a fixation cross appearing at the center of the screen for 0.5 s. A compound-fixation stimulus then appeared for 1 s, smoothly offsetting (over about 30 ms) to one of the compound-letter stimuli, which remained until the participant responded (or until 3 s had passed). The compound-letter stimuli were chosen with equal probability from one of the sixteen possible combinations (global size × organizational complexity × global-letter identity × local-letter identity). The participant's task was to indicate, by two consecutive key presses, the identity of the local letter and then the global letter, or vice versa, according to the instructions for the current block. If the participant made an error on either the first or second identification response, a beep was sounded, and the next trial was immediately begun.

Design

The experiment used a six-way mixed factorial design with Identification Order (global-local vs. local-global), Organizational Complexity (two-level vs. three-level), Global Size (large vs. small), Global-letter Identity (H vs. S), and Local-letter Identity (H vs. S) as within-participant factors, and Identification-order Block Order (global-local then local-global vs. local-global then global-local) as a between-participant factor. Only the first three factors are directly relevant to the theoretical questions of interest, and therefore only they were included in the reported analyses. A complete analysis of variance (ANOVA) summary table including all six factors is presented in Appendix III (Table A4).

Results and Discussion

Mean error rate and mean overall RT on correct-response trials was calculated for each participant in each of the eight experimental conditions: Identification Order × Organizational Complexity × Global Size (see Table 1). The RT means were trimmed by excluding responses more than 2.5 *SD* above or below the mean RT of each cell (4.9% of the trials). The error-rate and RT data were each analyzed using a three-way repeated measures ANOVA.

First examining the latency results, significant main effects of organizational complexity and global size were observed (see Figure 4): First, as predicted by the pure-object-based and object-based-spatial models (but contrary to the pure-space-based and direct-access models), overall RT was slower for three-level (1113 ms) than for two-level (1065 ms) stimulus structure, $F(1, 15) = 54.5$, $MSE = 2803$, $p < .001$, $\eta_p^2 = .78$. Second, as predicted by the pure-space-based and object-based-spatial models (but contrary to the pure-object-based and direct-access models), overall RT was slower for larger (1097 ms) than for smaller (1081 ms) global size $F(1, 15) = 10.0$, $MSE = 1511$, $p < .01$, $\eta_p^2 = .40$. There was no significant effect of identification order, or interactions between identification order and either global size or organizational complexity (all Fs < 2.0).

Taken as a whole, these results support the object-based-spatial model, which holds that both organizational and spatial factors affect attentional focusing: The time needed to focus or defocus attention between the global and local levels of a hierarchically structured stimulus object depends both on the magnitude of the required spatial adjustment of the attentional "aperture," and on the presence (or absence) of additional, intermediate levels of object structure that must be traversed.

An additional result that must be considered, however, is a significant interaction between organizational complexity and global size, $F(1, 15) = 9.4$, $MSE = 1339$, $p < .01$, $\eta_p^2 = .38$ (see Figure 4): The effect of organizational complexity was greater for the large global stimuli than for the small global stimuli, but was significant in both cases, $F(1, 15) = 55.9$, $MSE = 2263$, $p < .001$, $\eta_p^2 = .79$; and $F(1, 15) = 20.7$, $MSE = 1879$, $p < .001$, $\eta_p^2 = .58$; respectively. The effect of global size, however, was significant for the three-level stimuli, $F(1, 15) = 21.6$, $MSE = 1283$, $p < .001$, $\eta_p^2 = .59$, but not for the two-level stimuli, $F < 1$. This interaction might be taken to suggest that the spatial and organizational influences on attentional focusing are interdependent. However, it might also be the result of a marginal difference in perceptual discriminability of the global letters of the large and small two-level stimuli, suggested by a nonsignificant trend ($p = .08$) in the results of the stimulus-discriminability pretest (see Appendix I), by which the global letters of the large two-level stimuli were identified somewhat faster than the global letters of the small two-level stimuli. If reliable, a perceptual advantage of the large two-level stimuli compared to the small two-level stimuli might offset the expected focusing disadvantage (i.e., longer focusing time) of these stimuli, and thereby be responsible for the anomalous null effect of global size on overall RT for the two-level stimuli in the current experiment.

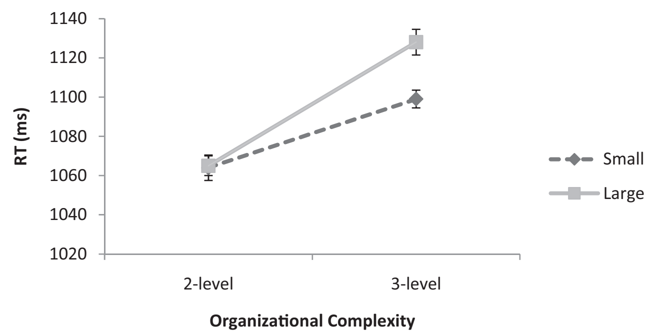

Figure 4. Results of Experiment 1. Mean correct response latency as a function of organizational complexity (two-level vs. three-level) and global size (large vs. small). Error bars in this and all following graphs represent within-participant 95% confidence intervals (see Cousineau, 2005; Morey, 2008).

Table 1
Mean Correct Response Latencies (RT; in Milliseconds) and Error Rates (Percentages) in the Experimental Conditions of Experiment 1

	Global → Local		Local → Global	
Global size	2-Level	3-Level	2-Level	3-Level
		RT		
Large	1078	1137	1053	1120
Small	1084	1108	1044	1090
		Error rate		
Large	3.9	4.4	4.2	5.4
Small	3.8	4.9	4.6	4.9

To address this possibility, we ran an additional set of participants ($N = 20$) on both the stimulus-discriminability pretest task and the dynamic hierarchical focusing task of Experiment 1, this time using a within-participants design and including the two-level stimuli only. The details and analyses of these follow-up data are presented in Appendix II. To summarize, in the additional follow-up data there was no sign of a difference in the discriminability of the large and small global letters, and accordingly, those subjects did yield the expected global size effect on overall RT for the two-level stimuli in the dynamic focusing task. A significant global size effect on overall RT for the two-level stimuli in the dynamic focusing task continued to be observed when the data from the follow-up participants were combined with those of the participants from Experiment 1. We thus conclude that there is no clear evidence that the spatial and organizational components of attentional focusing are interdependent.

Finally, to verify that the pattern of latency results observed in this experiment was not due to a speed-accuracy tradeoff, a similar ANOVA was conducted on the error rates. In line with the RT results, the main effect of organizational complexity approached significance, $F(1, 15) = 4.0$, $MSE = 1.0$, $p = .06$, $\eta_p^2 = .21$, reflecting a lower error rate for the two-level (4.1%) than for the three-level stimuli (4.9%). There was no effect of global size ($F < 1$). No other effects or interactions were significant (all Fs < 1).

Thus, there was no sign that the latency results might be due to a speed-accuracy tradeoff. Nevertheless, as a further check, we also calculated for each participant the within-individual correlation between RT and accuracy across all experimental trials, after trimming responses more than 2.5 *SD* above or below the mean RT (see Goldsmith & Yeari, 2003). These correlations averaged −.04 (*SD* = .06). Thus, if anything, shorter latencies were associated with greater accuracy within individuals, allaying any concerns about a speed-accuracy trade-off.

Experiment 2

The results of Experiment 1 suggest that the time needed to focus (or defocus) attention depends both on the magnitude of change in size of the attentional aperture (spatial component) and on the number of levels of hierarchical object structure that are traversed (organizational component).

The aim of the present experiment was to provide additional evidence for the organizational component of attentional focusing, and in particular, to reinforce the claim that the observed effect of organizational complexity reflects specifically the dynamics of attentional focusing. This experiment used a variant of the dynamic hierarchical focusing paradigm, comparing the pattern of performance for two different tasks at the local level: identification versus detection. On each trial, participants first fixated the neutral compound-letter stimulus (global 8 composed of local 8s). Simultaneous with the offset of a subset of local elements to create either a global H or S shape, on 75% of the trials a local singleton target was created by changing the color of one of the local letters from black to red, and its shape to either H or S; the other 25% were "catch" trials without a local singleton target. In the local *detection* condition, participants were instructed to respond first with a key press to indicate the identity of the global letter, and then respond as quickly as possible with a second key press if they detected the presence of the colored local target. The instructions for the local *identification* condition were identical, except that the participants were instructed to identify (rather than just detect) the local target letter (H or S) as quickly as possible after identifying the global letter.

We assumed that the local detection task could be performed without focusing attention to the local-level target, because local color changes and unique color singletons on a homogenous background can generally be detected easily under conditions of spread attention (e.g., Pashler, 1988; Treisman & Gelade, 1980), and in fact, are quite difficult to ignore, especially when they are relevant to the task (Belopolsky, Zwaan, Theeuwes, & Kramer, 2007; Turatto & Galfano, 2000).[4] In contrast, when performing the local identification task, we assumed that although focused attention would not be needed to detect or localize the target (Bravo & Nakayama, 1992), participants would nevertheless need to dynamically refocus their attention from the global letter to the local singleton target in order to discriminate the conjunctive line-feature relations of the target letter shape (Treisman & Gelade, 1980). Indeed, in prior research comparing the identification versus mere detection of singleton targets, focused attention was found to be needed for singleton identification but not for singleton detection (Bravo & Nakayama, 1992; Sagi & Julesz, 1984, 1985).

Based on the assumption that attention would need to be focused dynamically from the global to the local level to perform the local identification task, but not to perform the local detection task, the critical prediction was an interaction between local task type and organizational complexity (three-level vs. two-level structure): No effect of organizational complexity was predicted in the local detection condition. Although the local detection response is based on the feature (color) of a local element, there is no need for attention to dynamically refocus from the global to the local level, and hence, attention should not traverse the intermediate level of object structure of the three-level stimuli. In contrast, the dynamic focusing of attention to the local level in the local identification condition was expected to yield an organizational complexity effect, reflecting a longer focusing time for three-level stimuli than for two-level stimuli.

As in Experiment 1, the global size of the hierarchical stimuli was also manipulated. This was done primarily to maintain continuity with the earlier experiment, and to verify that the predicted interaction between organizational complexity and task type (identification vs. detection) would generalize across the two stimulus sizes. Note that unlike the effect of organizational complexity, the effect of global size on response latency in this experiment may include a direct effect of global size on the efficiency of detecting and localizing the local singleton target. As noted before, although we assume that the local singleton target can be detected easily under spread attention, the detection latency may nevertheless be sensitive to differences in the size of the area over which attention is spread (e.g., Laberge & Brown, 1986), such that participants may be somewhat slower to detect the local target with attention spread over the larger global letter than with attention spread over the smaller global letter. Thus, in the local detection condition, although no effect of global size on overall RT is expected to ensue from differences in the time needed for dynamic attentional focusing, an effect may nevertheless be observed because of size differences in the global spread of attention. Likewise, in the local identification condition, although we want to be able to attribute differences in overall RT for the large and small global stimuli to differences in dynamic focusing time alone, any observed differences could be contaminated by differences in the efficiency of detecting and localizing the element that must be discriminated. Because of these interpretational difficulties, the global size effects in this experiment will not be used to examine the spatial component of dynamic attentional focusing.

Method

Participants

Twenty undergraduate students at the University of Haifa participated in the experiment for payment (NIS 35) or course credit,

[4] Based on prior research, we assumed that the salient color singleton would produce "popout," and therefore would be easily detected without attentional focusing, even though detection latency might still be sensitive to the size of the attentional focus (e.g., Laberge & Brown, 1986; Turatto et al., 2000). In this regard, we refer to the local color change and not to the local shape change, because the latter is a more subtle, relational feature change that is not expected to produce pop-out. The shape change was included in the detection condition only to maintain maximum similarity to the corresponding identification condition.

in a 45-min session. All participants had normal or corrected-to-normal vision.

Apparatus and Stimuli

The apparatus and stimuli were identical to those used in Experiment 1, with the following differences: Each compound-letter stimulus was composed of neutral local 8 elements for the entire duration of the trial. On 75% of the trials, together with the offset of local elements to create the global H or S shape, the color of one of the remaining local elements was changed to red, and its shape was changed to either H or S (remaining so until the end of the trial). This single local target element was positioned randomly either 1.7° or 2.3° to the left or to the right of the center of the global stimulus. The same four local target positions were used for all four combinations of global size and organizational complexity.

Procedure

The procedure was identical to that used in Experiment 1, with the following differences: After the offset of the neutral compound fixation stimulus into the target stimulus, the participant's task was first to identity the global letter (by pressing the response key for H or S) and then respond to the local red target element, if present. Twenty five percent of the trials were "catch" trials, on which there was no local red target, and for which the participants were instructed to refrain from making a second response (after the global letter identification response). For the remaining 75% of the trials, in which a single local colored target appeared, participants were instructed to make a second response, depending on the task condition: (1) In the *local-detection* condition, the participants were instructed to press the "space bar" key (with the hand not used for the global identification response) as quickly as possible after making the global identification response. (2) In the *local-identification* condition, the participants were instructed to indicate whether the red local target was an H or an S (using the same response keys as for the global target letter).

The local detection task was performed in two consecutive blocks of 144 trials each, with an additional two blocks for the local identification task, with task order counterbalanced across participants. A block of 77 practice trials, identical to the corresponding experimental trials, preceded the first block of each task.

Design

The experiment used a six-way mixed factorial design with Local Task Type (detection vs. identification), Organizational Complexity (two-level vs. three-level), Global Size (large vs. small), Global-letter Identity (H vs. S), and Local-letter Identity (H vs. S) as within-participant factors; and Local Task Block Order (detection then identification vs. identification then detection) as between-participant factor. Again, only the first three factors are directly relevant to the theoretical hypotheses, and therefore only they were included in the reported analyses. A complete ANOVA summary table including all factors is presented in Appendix III (Table A5).

Results and Discussion

For target-present trials only, mean error rate and mean overall RT for correct responses was calculated for each participant in each of the eight experimental conditions: Local Task Type × Organizational Complexity × Global Size (see Table 2). The RT means were trimmed by excluding responses more than 2.5 *SD* above or below the mean RT of each cell (5.6%).

The first analysis was conducted on overall RT in the local-identification condition, to examine the prediction that an organizational complexity effect would be observed when attention must be focused dynamically from the global to the local level. A two-way ANOVA, Organizational Complexity (2-level vs. 3-level) × Global Size (large vs. small), revealed that overall RT was indeed slower for three-level stimuli (1020 ms) than for two-level stimuli (996 ms), $F(1, 19) = 13.7$, $MSE = 1611$, $p < .01$, $\eta_p^2 = .42$ (see Figure 5a). Thus, the organizational complexity effect observed in Experiment 1 was replicated and extended here to a hierarchical focusing task that requires focusing to a specific local element rather than to all local elements. There was also a main effect of global object size, with overall RT slower for larger (1018 ms) than for smaller (998 ms) global stimuli, $F(1, 19) = 17.2$, $MSE = 982$, $p < .001$, $\eta_p^2 = .48$. As discussed earlier, this effect might reflect the contribution of the spatial component of dynamic attentional focusing to overall RT, but it also might simply reflect more difficult localization of the target element when attention is maintained in a more widely spread distribution across the larger global object. Notably, there was no interaction between organizational complexity and global size, $F(1, 19) = 1.9$, $MSE = 618$, $\eta_p^2 = .09$, and the organizational complexity effect was significant for each of the global object sizes, analyzed separately.

Turning now to the local-detection condition, a similar analysis was conducted to examine the prediction that no organizational complexity effect would be observed in a task that requires a response to the presence of a local target element, but which does not require attention to be dynamically focused on that local element. As expected, there was no difference in overall RT between the three-level (876 ms) and two-level (870 ms) stimuli in the detection condition, $F(1, 19) = 1.1$, $MSE = 1287$, $\eta_p^2 = .05$, and no interaction between organizational complexity and global size, $F < 1$ (see Figure 5b). There was a significant main effect of global size, however, indicating faster overall RT for smaller (867 ms) than for larger (878 ms) global stimuli, $F(1, 19) = 5.1$, $MSE = 1003$, $p < .05$, $\eta_p^2 = .21$. As discussed earlier, this effect may simply reflect more difficult detection of the singleton target when attention is distributed more widely across the larger global object (cf. Eriksen & St. James, 1986; Laberge & Brown, 1986).

Table 2
Mean Correct Response Latencies (RT; in Milliseconds) and Error Rates (Percentages) in the Experimental Conditions of Experiment 2

	Detection		Identification	
Global size	2-Level	3-Level	2-Level	3-Level
		RT		
Large	876	881	1009	1027
Small	864	871	983	1012
		Error rate		
Large	2.4	1.9	1.3	2.3
Small	2.4	2.6	2.3	2.8

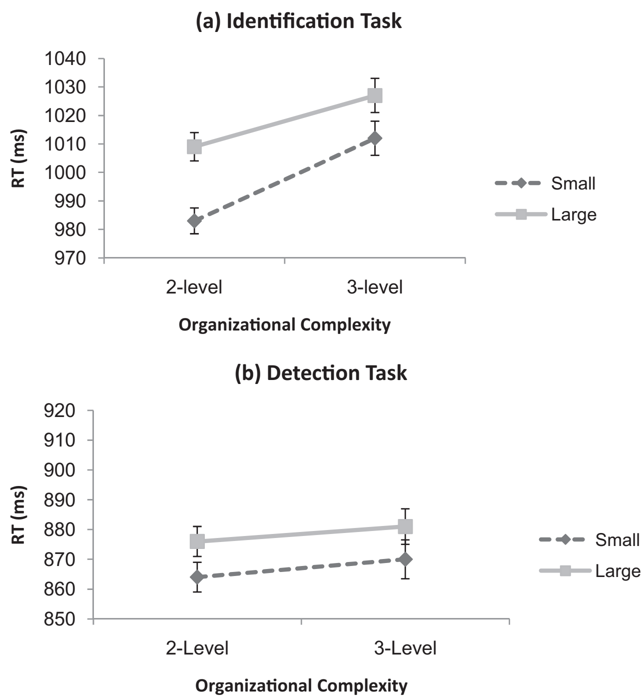

Figure 5. Results of Experiment 2. Mean correct response latency in the (a) identification and (b) detection conditions as a function of organizational complexity (two-level vs. three-level) and global size (large vs. small).

To verify the statistical significance of the different patterns of organizational-complexity effects in the identification and detection tasks, a three-way ANOVA was performed, Task Type (detection vs. identification) × Organizational Complexity (two-level vs. three-level) × Global Size (large vs. small). The predicted interaction between organizational complexity and task type was significant, $F(1, 19) = 5.0$, $MSE = 1248$, $p < .05$, $\eta_p^2 = .20$.[5]

Corresponding analyses were conducted on the error rates, mainly to verify that the preceding RT patterns were not due to a speed-accuracy tradeoff. For the identification task, a two-way ANOVA, Organizational Complexity (two-level vs. three-level) × Global Size (large vs. small), yielded a nonsignificant trend for organizational complexity in line with the RT results, $F(1, 19) = 3.4$, $MSE = 0.6$, $p = .08$, $\eta_p^2 = .14$, reflecting a marginally lower error rate for the two-level stimuli (1.8%) than for the three-level stimuli (2.5%). A significant global size effect, however, reflecting a lower error rate for the larger stimuli (1.8%) than the smaller stimuli (2.6%), $F(1, 19) = 7.3$, $MSE = 0.3$, $p < .05$, $\eta_p^2 = .30$, was observed in a direction opposite to the effect found on overall RT, suggesting that both may be due to a speed-accuracy tradeoff. A similar two-way ANOVA for the detection task yielded no significant effects or interactions (all Fs < 1). Again, these analyses were followed up by calculating the within-individual correlation between trimmed RT and accuracy. These correlations averaged $-.014$ ($SD = .07$) for the identification condition and .004 ($SD = .16$) for the detection condition, neither significantly different from zero. Thus, in partial contrast to the preceding error analysis, this correlational analysis yields no sign at all of a speed accuracy tradeoff.

Taken together, the results of this experiment support the prediction that organizational complexity effects should be observed only when attention is focused dynamically from the global to the local level (or vice versa), and hence are specifically a result of the hierarchical object-based component of attentional focusing. They also extend the finding of hierarchical object-based focusing to a situation in which a single local element must be focused on, as opposed to Experiment 1, in which any or all of the local elements might be focused on and identified.

Experiment 3

Experiment 3 was designed to provide a third and final examination of the organizational component of attentional focusing, to further reinforce the claim that the intermediate level of structure in three-level stimuli imposes a hierarchical constraint on dynamic attentional focusing, and to verify that the organizational-complexity effects observed so far do not merely reflect attentional “distraction” introduced by the presence (versus absence) of the intermediate-level rectangle shapes. It used essentially the same design and stimuli as in the previous experiments, but now the local target on each trial was a small isolated letter, equal in size to the local elements of the compound stimulus, but not hierarchically organized with that stimulus (i.e., not a component of the structured object). Instead, this local letter was located within either the upper or lower portion of the empty space that is partly bounded by the compound-letter stimulus (see Figure 6). As in the previous experiments, participants identified first the global letter and then the isolated local letter (focusing), or vice versa (defocusing). The organizational complexity and global size of the stimuli were orthogonally manipulated.

Because in this experiment, the intermediate level of the three-level stimuli does not lie on the hierarchical object-based route between the global and local targets, no effect of organizational complexity is predicted by the object-based or object-based-spatial models. In contrast, if performance is slower for the three-level compared to the two-level stimuli, this will suggest some amount of attentional distraction by the intermediate-level rectangles,

[5] Note that the combined complete-design (6-way) ANOVA of overall RT in the dynamic focusing task (Table A5, Appendix III) yielded a significant three-way interaction between task type, organizational complexity, and identity of the global letter: In the local-identification condition, overall RT was slower for three-level than two-level stimuli when the global letter was S, but not when it was H; there was no such interaction (no effect of organizational complexity under any conditions) in the local-detection condition. The interaction with global letter identity in the local-identification condition may stem from a difference in the discriminability of the global letters of two-level and three-level stimuli that emerged in the complete-design analysis of the pretest data (see Appendix III, Table A7, note *e*). There it was found that identifying a global H letter composed of local S elements was slower for two-level stimuli than for three-level stimuli, with nonsignificant effects of organizational complexity in all of the other seven combinations of target level × global-letter identity × local-letter identity. Such a discriminability difference would work against the predicted effect of organizational complexity on overall RT in the dynamic focusing task, and is also suggested by the results of Experiment 1, in which the organizational-complexity effect was more pronounced for global-S than for global-H stimuli, though significant in both cases (see Appendix III, Table A4, note *e*).

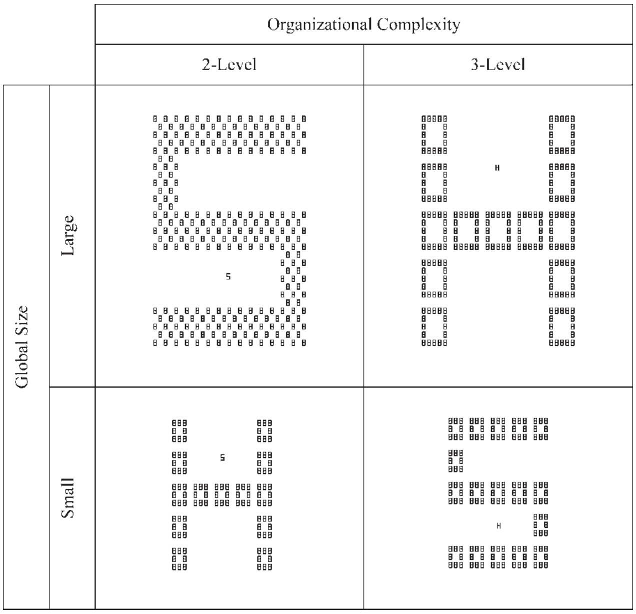

Figure 6. Examples of the stimulus displays used in Experiment 3: a hierarchical compound letter and a small isolated letter located in either the upper or lower region of space encompassed by the compound letter.

which may have contributed to the organizational-complexity effects observed in the preceding experiments.

Method

Participants

Sixteen undergraduate students at the University of Haifa participated in the experiment for payment (NIS 35) or course credit, in a 45-min session. All participants had normal or corrected-to-normal vision.

Apparatus and Stimuli

The apparatus and stimuli were identical to those used in Experiment 1, with the addition of a small isolated letter, the same size as the local elements of the compound letter, presented within the open space bounded by the compound letter (see Figure 6). This isolated letter was located either 3.25° above or below the center of the compound stimulus, and either 2.12° above or below the center of the small stimulus (positioning above or below center was chosen randomly). The global shape of the compound letter and the identity of the small isolated letter could be either S or H, as the local elements of the compound letter were always neutral 8 digits.

Procedure

The procedure was identical to that used in Experiment 1, except that the small isolated letter took the role of the local letters of the compound-letter stimulus in the previous experiment, both in terms of the target that needed to be responded to, and in terms of the element that was fixated on and then gradually offset from a neutral 8 shape on the local-global trials. (The local letters of the compound-letter stimulus remained in the neutral 8 shape throughout each trial.)

Design

The experiment used the same six-way mixed factorial design as in Experiment 1: Identification Order (global-local vs. local-global), Organizational Complexity (two-level vs. three-level), Global Size (large vs. small), Global-letter Identity (H vs. S), and Local-letter Identity (H vs. S) as within-participant factors, and Identification-order Block Order (global-local then local-global vs. local-global then global-local) as a between-participant factor. Only the first three factors are directly relevant to the theoretical hypotheses, and therefore only they were included in the reported analyses. A complete ANOVA summary table including all six factors is presented in Appendix III (Table A6).

Results and Discussion

Mean error rate and mean overall RT on correct-response trials was calculated for each participant in each of the eight experimental conditions: Identification Order × Organizational Complexity × Global Size (see Table 3). The RT means were trimmed by excluding responses more than 2.5 *SD* above or below the mean RT of each cell (5.6% of all trials). The RT and error-rate data were each analyzed using a three-way repeated measures ANOVA.

Examining first the latency results, significant main effects were observed for organizational complexity and global size (see Figure 7), as well as a significant interaction between global size and identification order: First, overall RT was slower for the three-level stimuli (955 ms) than for the two-level stimuli (943 ms), $F(1, 15) = 5.9$, $MSE = 1500$, $p < .05$, $\eta_p^2 = .28$, suggesting a small amount of attentional distraction (12 ms). Second, overall RT was slower for the larger compound-letter stimuli (958 ms) than for the smaller compound-letter stimuli (939 ms), $F(1, 15) = 5.9$, $MSE = 1481$, $p < .05$, $\eta_p^2 = .52$, suggesting a spatial influence on attentional focusing. This effect, however, was qualified by a significant global-size × identification-order interaction, $F(1, 15) = 11.6$, $MSE = 1079$, $p < .01$, $\eta_p^2 = .44$, reflecting the fact that global size affected performance in the global-local identification order condition, $F(1, 15) = 26$, $MSE = 1366$, $p < .001$, $\eta_p^2 = .63$, but not in the local-global condition, $F < 1$. The reason for this interaction is unclear.

Table 3
Mean Correct Response Latencies (RT; in Milliseconds) and Error Rates (Percentages) in the Experimental Conditions of Experiment 3

	Global → Local		Local → Global	
Global size	2-Level	3-Level	2-Level	3-Level
		RT		
Large	958	981	943	954
Small	930	941	942	944
		Error rate		
Large	2.7	3.9	4.1	2.7
Small	3.2	4.4	4.4	3.2

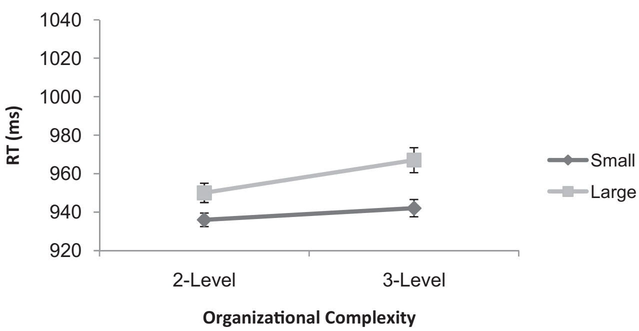

Figure 7. Results of Experiment 3. Mean correct response latency as a function of organizational complexity (two-level vs. three-level) and global size (large vs. small).

The main finding of interest is the significant effect of organizational complexity, which in this experiment can be interpreted as an attentional distraction effect. To determine whether this distraction effect might be responsible for the organizational-complexity effect observed in Experiment 1, we added Experiment to the design as a between-participants factor, and examined the Organizational Complexity × Experiment interaction in a four-way repeated measures ANOVA. This interaction was highly significant, $F(1, 30) = 20.5$, $MSE = 2151$, $p < .001$, $\eta_p^2 = .43$, implying that the 48 ms organizational-complexity effect observed in Experiment 1 cannot be explained solely in terms of attentional distraction, whose effect was only 12 ms in the present experiment.

Turning now to the accuracy results of the present experiment, a three-way ANOVA on the error rates yielded an effect of organizational complexity that approached statistical significance, $F(1, 15) = 4.0$, $MSE = 0.9$, $p = .06$, $\eta_p^2 = .21$, reflecting a trend toward a higher error rate for the three-level stimuli (4.2%) than for the two-level stimuli (3.4%). This trend is of the same (small) magnitude observed in Experiment 1 earlier ($F < 1$ for the difference). Thus, it is possible that the earlier accuracy trend reflects attentional distraction only. No other effects or interactions were significant. Again, the accuracy analysis was followed up by calculating the within-individual correlation between trimmed RT and accuracy across all experimental trials. These averaged −.073 ($SD = .072$). Thus, by both analyses, there is no sign of a speed-accuracy trade-off.

General Discussion

The present study explored the nature of attentional focusing, with particular regard to its organizational and spatial aspects. For this purpose, four basic models were compared using a dynamic hierarchical attentional focusing task, requiring sequential identification of global and local target letters of a single, hierarchically structured compound-letter object, in a single trial. On the whole, the results supported the object-based-spatial model, which holds that attentional focusing is sensitive to both spatial and hierarchical-organizational factors: The time needed for attentional focusing was found to increase both with the magnitude of the change in size of the attentional aperture and with the number of levels of object structure that are traversed, with the results supporting the organizational aspect somewhat more consistent and robust than those supporting the spatial aspect.

Regarding the organizational component, strong organizational complexity effects (slower overall RT for the three-level than the two-level stimuli) were observed in Experiment 1 for both focusing (global-to-local shifts) and defocusing (local-to-global shifts), with both large and small global objects. Null effects of organizational complexity in the single-level identification pretest task (Appendix I; with one significant difference in the opposing direction, see Appendix III, Table A7, note *e*), discount the possibility that the organizational effects observed in the dynamic focusing task stem merely from differences in perceptual discriminability. In Experiment 2, as predicted, organizational-complexity effects were observed in the local target identification task, which required attentional focusing from the global to the local level, but not in the local target detection task, which did not require attentional focusing. This result reinforced the claim that the observed organizational-complexity effects specifically reflect the dynamics of attentional focusing, and extended the evidence for hierarchical, object-based focusing to the case in which a specific local element is being focused. Finally, the results of Experiment 3 reinforced the claim that the organizational-complexity effects specifically reflect the focusing of attention along a hierarchical object-based route: When the local target was an isolated letter with no hierarchical relation between it and the global-level target of the compound-letter object, only a very weak effect of organizational complexity was observed—much weaker than the effect observed in Experiment 1, in which the intermediate level of the three-level objects constituted an intervening node on the hierarchical route between the global and local targets. We assume that the small residual difference in overall RT between the three-level and two-level objects in this experiment reflects a small amount of distraction caused by the intermediate-level rectangles of the three-level stimuli.

With regard to the spatial component, global size effects (slower overall RT for the larger than the smaller global objects) were somewhat less robust: In Experiment 1, they were initially observed for the three-level but not for the two-level stimuli, but when the data from that experiment were combined with follow-up data designed to clarify this issue (Appendix II), a significant global size effect was found for the two-level stimuli as well. In addition, in Experiment 3, which required focusing from the global letter of the compound-letter object to a small isolated letter, or vice versa, a global size effect was found in the former case (focusing) but not in the latter (defocusing). The less robust effects of global size might suggest that the spatial component of attentional focusing is relatively weak compared to the organizational component. Alternatively, they might simply indicate that the global size manipulation in our study was too moderate: Perhaps a larger global size difference would reveal the spatial component more strongly. Also, there was a nonsignificant trend (see Appendices I and II) suggesting that the larger global letters may have been somewhat easier to discriminate than the smaller global letters of the two-level stimuli, which could partly offset the expected effect of global size on attentional focusing time for these stimuli.

It should be noted that the present findings of both organizational-complexity and global-size effects on the time needed to focus attention clearly refute the direct-access model, which holds that attentional focusing is neither spatially nor organizationally constrained. Nevertheless, it is still possible that attention is focused in a “discrete” rather than “analog” manner, in the sense that attention shifts from one hierarchical level to another without passing through all of the intervening spatial settings (cf. the corresponding issue with regard to attentional orienting/movement; e.g., Egly & Homa, 1991). Specific ways in which the organizational and spatial components of attentional focusing might be realized are discussed next.

Role of Object Structure and Space in Attentional Focusing

The results just summarized indicate that the process of attentional focusing has both organizational and spatial components. However, the specific manner in which the two types of factors jointly contribute to this process has yet to be determined. Various possibilities can be conceived, which differ in the relative primacy of each component. For example, assuming that the spatial component is primary, attention might be conceived as focusing within a spatial medium, but one in which perceptual objects are also represented at various spatial scales. Attentional focusing would then be carried out in an analog manner, but whenever a new perceptual object (at any hierarchical level) is encompassed by the attentional aperture, the perceptual object is automatically selected (or “engaged”; see Brown & Denny, 2007), with the size and shape of the aperture being adjusted to conform to the boundaries of that object. Attention might be maintained on that object if it is a “target”; otherwise the analog focusing operation would continue until the next perceptual object is encountered.

Along these lines, Turatto et al. (2000) demonstrated that when a new object suddenly appears in the visual field, the focus of attention is automatically fitted to it, but then an endogenous effort must be made to keep attention in a focused mode. They also showed that voluntary focusing needs a perceptual object on which to operate, with participants being unable to maintain a focused mode of attention to empty space. This view of the attentional focusing process is also quite similar to the object-based-spatial (e.g., Arrington et al., 2000) and “grouped array” (Vecera, 1994; Vecera & Farah, 1994) views of attentional selection, in which the boundaries of the unit of selection are constrained by Gestalt grouping principles and uniform connectedness, but what is being selected is essentially a unit of space.

By contrast, it might be that the organizational-hierarchical component of attentional focusing is primary, such that attention is constrained to focus from node-to-node (perceptual object to perceptual object) in a hierarchical, object-based representation, with shifts of focus performed discretely rather than in an analog manner. The observed global size effects on focusing time might then be explained by the fact that although the object-based hierarchy dictates the route, the attentional aperture is readjusted to the size of each engaged perceptual object, with larger adjustments taking longer to perform than smaller adjustments.

Previous research has examined the nature of attentional selection within hierarchical stimuli in terms of a *hierarchical priming effect*—the finding that the processing of a global or local target is faster when the target was processed at the same hierarchical level on the preceding trial (e.g. Ward, 1982, 1985). The debate in that context has centered on whether the hierarchical levels are selected *regionally* or *categorically* (e.g., Lamb & Robertson, 1988; Robertson, Egly, Lamb, & Kerth, 1993; Stoffer, 1993): According to the spatial-regional hypothesis, different hierarchical levels are selected by varying the diameter of an attentional spotlight, with a processing advantage when the same diameter can be maintained across trials. In contrast, according to the categorical hypothesis, some attribute that distinguishes the global and local shapes (e.g., spatial frequency; Lamb & Yund, 1996, 2000; Robertson et al., 1993) serves as the basis for selecting information at one level or the other, and a processing advantage ensues when the same feature is maintained across trials. The pattern of findings is quite complex, with Kim, Ivry, and Robertson (1999), for example, finding evidence of both regional and categorical selection.

It is tempting, but premature, to draw a straightforward correspondence between the evidence for regional and categorical selection in the studies just mentioned, and the evidence for spatial and organizational components of attentional focusing, respectively, in the present study. The finding that the unit of selection is (sometimes) a region of space of a particular size does not necessarily imply that changes in the size of that region (i.e. focusing and defocusing) will be performed in a spatial-analog manner, with focusing time a function of the magnitude of the change in the size of the attended region. Perhaps even more clearly, the finding that the unit of selection is (sometimes) a particular spatial frequency does not imply that changes in the attended level will be performed in a hierarchical object-based manner. In general, the nature of the unit of attentional selection and the manner in which attention is shifted from selected unit to selected unit are not necessarily interdependent, and so it is important to examine and clarify each of these separate aspects to gain a more complete picture of how attention operates within a hierarchically structured visual world.

Mandatory vs. Default Constraints on Attentional Focusing

So far, we have been interpreting the results of the present study as indicating both organizational and spatial constraints on attentional focusing. However, it may be that hierarchical object-based attentional focusing actually reflects a default tendency rather than a mandatory constraint. Indeed, recent studies have demonstrated that even under conditions in which an object is perceptually represented and, by default, guides attentional selection, observers are able to avoid this guidance when there is a clear strategic benefit in doing so (Shomstein & Behrmann, 2008; Yeari & Goldsmith, 2010). Based on such findings, Yeari and Goldsmith (2010; see also Shomstein & Yantis, 2004) proposed that object-based attention is a default rather than mandatory mode of attentional selection: a tendency to select perceptual objects rather than unparsed regions of space, which constrains attention unless there is a strong and clear reason to resist this tendency. Thus, it is possible that observers might be able to avoid focusing and defocusing through intervening levels of object structure on the hierarchical object-based route if there is a strong enough incentive to do so. In the present study, hierarchical object-based attentional focusing was not avoided, even though this slowed down response times for the three-level objects. This suggests that either hierarchical object-based focusing is mandatory, or that a stronger incentive may be needed to induce observers to resist the tendency to follow the hierarchical route.

Functional arguments can be made regarding why hierarchical attentional focusing might be ecologically adaptive: Traversing through higher levels of structure to reach lower levels of structure in the visual scene may generally be beneficial, because higher levels tend to organize the lower level units and may provide meaningful information about those units when scanning our surroundings (Rauschenberger & Yantis, 2001; Shomstein & Yantis, 2002; Yantis & Hillstrom, 1994; Yantis & Jonides, 1996). Consider once again the table-platter-plate-food example used earlier. It will generally be more expedient to search for different pieces of food on the table according to their intermediate organization into platters and plates, rather than as an unorganized assortment of food on the table. For this reason, hierarchical focusing may actually be strategically expedient, even though, as indicated by the results of the current experiments, there is a small cost in traversing and accessing additional object levels. Presumably, there will be cases in which the advantage of an organized focusing strategy will more than compensate for the additional access cost. For example, this may be particularly true in search tasks, in which the search for a target element at a relatively local level might be facilitated by segmentation and organization into homogenous groups at a higher hierarchical level (see, e.g., Treisman, 1982; Treisman & Sato, 1990). It should be interesting to investigate whether organizational complexity effects might actually reverse (e.g., faster RT for three-level than two-level stimuli) in cases in which search is involved and the more global structure provides useful information about the likely target location (cf. Chun & Jiang, 1998).

Of course, much work remains to examine the generality of the present findings for different types of tasks and objects, and to identify potential boundary conditions. An important further implication that should be examined is the influence of the hierarchical organization of the visual field on attentional navigation that includes both orienting and focusing. For example, in shifting one's attention between the local levels of two different hierarchically structured objects, does attention follow a hierarchical route, defocusing through the origin object and then refocusing through the destination object? Preliminary results from our lab suggest that it does.

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(*Appendices follow*)

Appendix I

As the final stage of developing the hierarchical compound stimuli for use in this study, a pretest experiment was run with 19 participants to examine whether the global-size manipulation (large vs. small) or the stimulus-complexity manipulation (two-level vs. three-level) would unintentionally cause differences in the perceptual discriminability of the global or local letters (S or H). Unlike in the other experiments, this experiment required only a single response on each trial: to identify the letter(s) at either the local or global level, but not both, with target level manipulated between blocks. Otherwise, the procedure was identical to that used in Experiment 1, including a compound-fixation stimulus that offset smoothly from neutral 8 digits into the target compound-letter stimulus, allowing attention to be fixated initially at the target level, before the target letters were exposed. In this way, differences between the stimulus conditions in the time needed to focus attention at the appropriate level were eliminated, leaving only possible differences in perceptual discriminability that could potentially affect identification latency or accuracy.

The experiment used a six-way mixed factorial design with Target Level (global vs. local), Organizational Complexity (two-level vs. three-level), Global Size (large vs. small), Global-letter Identity (H vs. S), and Local-letter Identity (H vs. S) as within-participant factors, and Target Level Block Order (global then local vs. local then global) as a between-participant factor. Only the first three factors are directly relevant to the theoretical questions of interest, and therefore only they were included in the analyses reported here. A complete ANOVA summary table including all factors is presented in Appendix III (Table A7).

Mean correct RT and error rates for all combinations of target level, organizational complexity and global size are presented in Table A1. These means are based on 80 trials (repetitions) for each participant in each of the eight experimental cells. A three-way repeated-measures ANOVA, Target Level (global vs. local) $\times$ Organizational Complexity (two-level vs. three-level) $\times$ Global Size (large vs. small), on RT yielded a significant effect for target level, with slower identification of the global (581 ms) than the local (557 ms) letters, $F(1, 18) = 5.8$, $MSE = 4360$, $p < .05$, $\eta_p^2 = .24$. Of more relevance to the purpose of the pretest, there were no main effects of organizational complexity or of global size (both Fs < 1). There was, however, a significant interaction between global size and target level, $F(1, 18) = 9.1$, $MSE = 875$, $p < .01$, $\eta_p^2 = .34$, reflecting a nonsignificant trend toward faster identification of the global target of large ($M = 571$ ms) compared to small stimuli ($M = 591$ ms), $F(1, 18) = 3.5$, $MSE = 2158$, $p = .08$, $\eta_p^2 = .16$, with no such trend for the identification of local targets, $F < 1$. None of the other interactions were significant (all Fs ≤ 2.1).

Table A1
Mean Correct Response Latencies (RT; in Milliseconds) and Error Rates (Percentages) in the Experimental Conditions of the Stimulus-Discriminability Pretest

	Global level		Local level	
Global size	2-Level	3-Level	2-Level	3-Level
RT				
Large	571	571	554	566
Small	595	588	549	553
Error rate				
Large	3.2	2.6	1.6	1.6
Small	3.7	3.4	2.3	2.6

The absence of main effects for both organizational complexity and global size across the global and local target levels is crucial. It implies that there should be no general advantage or disadvantage in overall RT in the dynamic hierarchical focusing task stemming from differences in target discriminability of stimuli with two-level versus three-level hierarchical structure or small versus large global size, given that the focusing task requires target identification at both the global and local levels (sequentially) on each trial. Nevertheless, the nonsignificant trend toward faster identification of the global target of large versus small global stimuli gave rise to some concern, because such a difference, if reliable, might work against the spatial model in the dynamic hierarchical focusing paradigm, which predicts longer focusing time (and hence longer overall RT) for the larger global stimuli because of the greater size difference between the global and local levels in those stimuli. This potential problem did in fact arise in Experiment 1 (a null effect of global size for two-level stimuli) and was subsequently addressed by the collection of additional data, reported in Appendix II.

The same three-way ANOVA was also performed on the error rates (see Table A1). No significant effects or interactions were observed in these analyses (all Fs < 1.8). Also the within-individual correlation between trimmed RT and accuracy across all experimental trials averaged $r = .017$ ($SD = .14$), not significantly differ from zero. Thus, there is no sign of a speed-accuracy trade-off in these results.

(*Appendices continue*)

Appendix II

Table A2
Mean Correct Response Latencies (RT in Milliseconds) and Error Rates (Percentages) of Follow-Up Data Clarifying the Effect of Global Size on Performance for 2-Level Stimuli in the Single-Level Identification (Stimulus Discriminability) and Successive-Level Identification (Dynamic Hierarchical Attentional Focusing) Tasks

	Single-level identification		Successive-level identification	
Global size	Global	Local	Global → Local	Local → Global
		RT		
Large	569	539	1085	1094
Small	571	528	1063	1063
		Error rate		
Large	2.2	2.0	3.9	4.1
Small	1.9	1.1	4.8	3.1

Table A3
Mean Correct Response Latencies (RT; in Milliseconds) and Error Rates (Percentages) of the Follow-Up Data Combined With the Corresponding Data for the 2-Level Stimuli From the Stimulus-Discriminability Pretest (Single-Level Identification Task) and From Experiment 1 (Successive-Level Identification, Dynamic Hierarchical Attentional Focusing Task)

	Single-level identification		Successive-level identification	
Global size	Global	Local	Global → Local	Local → Global
		RT		
Large	570	547	1081	1073
Small	584	540	1073	1054
		Error rate		
Large	2.8	1.8	3.9	4.2
Small	2.8	1.7	4.3	3.9

To clarify the spatial component of attentional focusing with two-level stimuli in Experiment 1, follow-up data were collected for 20 additional participants in a within-participants design. Participants performed both the dynamic hierarchical focusing task (as in Experiment 1) and the single-level target identification task (as in the stimulus discriminability pretest; Appendix I) in separate blocks in counterbalanced order, using only the two-level stimuli.

Mean error rate and mean response time on correct-response trials were calculated for each participant in each of eight experimental conditions (see Tables A2 and A3): Task Type (single-level identification or dynamic focusing) × Target Level/Order (global only or local only for the single-level identification task; global-local or local-global for the dynamic focusing task) × Global Size (large vs. small). Of immediate interest is that unlike in Experiment 1, for these additional participants the effect of the global size of the two-level stimuli on overall RT in the dynamic focusing task was significant, with slower identification of the larger (1089 ms) than the smaller (1062 ms) global two-level stimuli, $F(1, 19) = 8.6$, $MSE = 3210$, $p < .01$, $\eta_p^2 = .31$. Moreover, in contrast to what the pretest results had suggested, there was no evidence that large global letters were discriminated faster than small global letters ($F < 1$).

In light of this, and in order to achieve maximal statistical power, we combined the data from the 20 follow-up participants with the corresponding data for the two-level stimuli from the original participants (both Experiment 1 and pretest). In this combined analysis, there was again a nonsignificant trend toward faster single-level identification of the larger global letters (570 ms) than the smaller global letters (583 ms), $F(1, 38) = 3.7$, $MSE = 5324$, $p = .07$, $\eta_p^2 = .58$. Nevertheless the effect of global size on overall RT in the dynamic focusing task remained significant, $F(1, 31) = 5.5$, $MSE = 2485$, $p < .05$, $\eta_p^2 = .34$, with slower overall RT for the larger two-level stimuli (1077 ms) than for the smaller two-level stimuli (1063 ms). A complete ANOVA summary table for the combined five-way analysis of overall RT for the two-level stimuli in the dynamic focusing task is presented in Appendix III (Table A8).[6]

[6] Note that the combined complete-design (6-way) ANOVA of overall RT for two-level stimuli in the dynamic focusing task (Table A8, Appendix III) yielded a significant interaction between global size and identification-order block order, such that the global size effect was statistically significant when the local-global (defocusing) block preceded the global-local (focusing) block, but not when these blocks were performed in the opposite order. This interaction was further qualified by a four-way interaction involving the specific identities of the global and local letters. We are unable to explain these interactions, but they, together with a further interaction with identification order in Experiment 3 (in which the global size effect was significant for global-local focusing but not for local-global defocusing) contribute to our general conclusion that the evidence supporting the spatial component of focusing in this study is less robust than that obtained in support of the organizational component (see General Discussion).

(*Appendices continue*)

Taken together, these results continue to suggest a trend toward marginally greater discriminability of the larger compared to the smaller global letters of the two-level stimuli. Yet, both in the follow-up data alone and in the combined analysis, the effect of global size on the time needed to focus attention in the dynamic focusing task revealed a spatial component of attentional focusing for these stimuli. This, of course, is in addition to the significant effect of global size on dynamic attentional focusing for the three-level stimuli, observed earlier in Experiment 1.

To verify that the preceding pattern of latency results was not compromised by a speed-accuracy tradeoff, the same set of analyses performed on RT was also performed on the error rates. No significant effects of global size or interactions involving that factor were observed in these analyses (all Fs < 2.0). We also calculated the within-individual correlation between trimmed RT and accuracy. These averaged .024 ($SD = .10$) for the single-level identification condition and –.009 ($SD = .12$) for the dynamic focusing condition; neither significantly different from zero. Thus, there was no sign of a speed-accuracy trade-off.

Appendix III

This appendix presents the complete-design ANOVA summary tables for each of the experiments (including appendices). Footnotes below each table clarify interactions that are significant ($p < .05$) or nearly significant ($p = .06$) that involve either of the main theoretical variables (organizational complexity or global size).

Table A4
Six-Way ANOVA on Experiment 1 RT Data

Source[a,b]	MS_{effect}	MS_{error}	F	p
Ord_B	508247	915019	0.6	.47
GSize	26605	2485	10.7	.01
OC	304437	5867	51.9	.01
ID_{Glob}	307972	12535	24.6	.01
ID_{Loc}	78247	8461	9.2	.01
Ord_{ID}	110224	31378	3.5	.08
OC × Ord_B	44	5867	0.1	.93
ID_{Glob} × Ord_B	56794	12535	4.5	.05
ID_{Loc} × Ord_B	6499	8461	0.8	.40
Ord_B × Ord_{ID}	172536	31378	5.5	.03
OC × GSize	26633	2873	9.3	.01[c]
GSize × ID_{Glob}	3338	3369	1.0	.34
GSize × ID_{Loc}	1514	1177	1.3	.28
GSize × Ord_B	11491	2485	4.6	.05[d]
Ord_{ID} × GSize	2007	1285	1.6	.23
OC × ID_{Glob}	18350	1064	17.2	.01[e]
OC × ID_{Loc}	3569	2521	1.4	.25
Ord_{ID} × OC	5412	2665	2.0	.18
ID_{Glob} × ID_{Loc}	2467482	20957	117.7	.01
Ord_{ID} × ID_{Glob}	12282	6163	2.0	.18
Ord_{ID} × ID_{Loc}	24568	3362	7.3	.02
OC × GSize × Ord_B	1452	2873	0.5	.49
GSize × ID_{Glob} × Ord_B	55	3369	0.1	.90
GSize × ID_{Loc} × Ord_B	2812	1177	2.4	.14
Ord_{ID} × GSize × Ord_B	712	1285	0.6	.47
OC × ID_{Glob} × Ord_B	250	1064	0.2	.64
OC × ID_{Loc} × Ord_B	238	2521	0.1	.76
Ord_{ID} × OC × Ord_B	14534	2665	5.5	.03[f]
ID_{Glob} × ID_{Loc} × Ord_B	6296	20957	0.3	.59

(*Appendices continue*)

Table A4 (*continued*)

Source[a,b]	MS_{effect}	MS_{error}	*F*	*p*
$Ord_{ID} \times ID_{Glob} \times Ord_B$	34348	6163	5.6	.03
$Ord_{ID} \times ID_{Loc} \times Ord_B$	2378	3362	0.7	.41
$OC \times GSize \times ID_{Glob}$	3568	4564	0.8	.39
$OC \times GSize \times ID_{Loc}$	1314	1867	0.7	.42
$Ord_{ID} \times OC \times GSize$	933	2208	0.4	.53
$GSize \times ID_{Glob} \times ID_{Loc}$	1480	3329	0.4	.52
$Ord_{ID} \times GSize \times ID_{Glob}$	4731	2956	1.6	.23
$Ord_{ID} \times GSize \times ID_{Loc}$	3707	2951	1.3	.28
$OC \times ID_{Glob} \times ID_{Loc}$	25463	4551	5.6	.03[g]
$Ord_{ID} \times OC \times ID_{Glob}$	3344	3014	1.1	.31
$Ord_{ID} \times OC \times ID_{Loc}$	4494	4805	0.9	.35
$Ord_{ID} \times ID_{Glob} \times ID_{Loc}$	57264	10764	5.3	.04
$OC \times GSize \times ID_{Glob} \times Ord_B$	28	4564	0.1	.94
$OC \times GSize \times ID_{Loc} \times Ord_B$	7350	1867	3.9	.07
$Ord_{ID} \times OC \times GSize \times Ord_B$	635	2208	0.3	.60
$Ord_{ID} \times GSize \times ID_{Glob} \times Ord_B$	2015	2956	0.7	.42
$GSize \times ID_{Glob} \times ID_{Loc} \times Ord_B$	11999	3329	3.6	.08
$Ord_{ID} \times GSize \times ID_{Loc} \times Ord_B$	1	2951	0.1	.99
$OC \times ID_{Glob} \times ID_{Loc} \times Ord_B$	4209	4551	0.9	.35
$Ord_{ID} \times OC \times ID_{Glob} \times Ord_B$	11942	3014	4.0	.07
$Ord_{ID} \times OC \times ID_{Loc} \times Ord_B$	14	4805	0.1	.96
$Ord_{ID} \times ID_{Glob} \times ID_{Loc} \times Ord_B$	31484	10764	2.9	.11
$OC \times GSize \times ID_{Glob} \times ID_{Loc}$	4151	2251	1.8	.20
$Ord_{ID} \times OC \times GSize \times ID_{Glob}$	127	3051	0.1	.84
$Ord_{ID} \times OC \times GSize \times ID_{Loc}$	967	1141	0.8	.37
$Ord_{ID} \times GSize \times ID_{Glob} \times ID_{Loc}$	7494	2714	2.8	.12
$Ord_{ID} \times OC \times ID_{Glob} \times ID_{Loc}$	14	3083	0.1	.95
$OC \times GSize \times ID_{Glob} \times ID_{Loc} \times Ord_B$	580	2251	0.3	.62
$Ord_{ID} \times OC \times GSize \times ID_{Glob} \times Ord_B$	1210	3051	0.4	.54
$Ord_{ID} \times OC \times GSize \times ID_{Loc} \times Ord_B$	650	1141	0.6	.46
$Ord_B \times GSize \times ID_{Glob} \times ID_{Loc} \times Ord_{ID}$	241	2714	0.1	.77
$Ord_{ID} \times OC \times ID_{Glob} \times ID_{Loc} \times Ord_B$	1234	3083	0.4	.54
$Ord_{ID} \times OC \times GSize \times ID_{Glob} \times ID_{Loc}$	150	4464	0.1	.86
$Ord_{ID} \times OC \times GSize \times ID_{Glob} \times Ord_B \times ID_{Loc}$	45	4464	0.1	.92

[a] Ord_{ID} = Identification Order (global-local vs. local-global); OC = Organizational Complexity (2-level vs. 3-level); GSize = Global Size (large vs. small); ID_{Glob} = Global-letter Identity (H vs. S); ID_{Loc} = Local-letter Identity (H vs. S); Ord_B = Identification-order Block Order (global-local then local-global vs. local-global then global-local). [b] $df_{effect} = 1$ and $df_{error} = 14$ for the entire analysis. [c] Two-way interaction reflecting a significant global size effect (slower overall RT for larger than smaller global stimuli) for 3-level stimuli, with no such difference for 2-level stimuli (see Experiment 1 and Appendix II for discussion). [d] Two-way interaction reflecting a more pronounced global size effect (slower overall RT for larger compared to smaller global stimuli) when the local-global (defocusing) block preceded the global-local (focusing) block than in the opposite block order, with the global size effect only approaching significance in the latter condition. [e] Two-way ordinal interaction indicating that the organizational complexity effect (slower overall RT for 3-level than 2-level stimuli) was more pronounced when the global letter was S than when it was H, but was significant in both cases. [f] Three-way ordinal interaction indicating that the organizational complexity effect (slower overall RT for 3-level than 2-level stimuli) was more pronounced for some combinations of identification order and identification-order block order, but was statistically significant in all cases. [g] Three-way ordinal interaction indicating that the organizational complexity effect (slower overall RT for 3-level than 2-level stimuli) was more pronounced for some combinations of global-letter identity and local-letter identity, but was statistically significant in all cases.

(*Appendices continue*)

Table A5
Six-Way ANOVA on Experiment 2 RT Data[a]

Source[b,c]	MS_{effect}	MS_{error}	F	p
Ord_B	136036	618157	0.2	.64
GSize	36526	1768	20.7	.01
OC	24679	3758	6.6	.02
ID_{Glob}	146925	19942	7.4	.01
ID_{Loc}	7446	7927	0.9	.35
Task	2918815	75629	38.6	.01
OC × Ord_B	1496	3758	0.4	.54
ID_{Glob} × Ord_B	86898	19942	4.4	.05
ID_{Loc} × Ord_B	456	7927	0.1	.81
Task × Ord_B	471	75629	0.1	.94
OC × GSize	159	1171	0.1	.72
GSize × ID_{Glob}	18486	3324	5.6	.03
GSize × ID_{Loc}	4545	1662	2.7	.12
GSize × Ord_B	267	1768	0.2	.70
Task × GSize	8690	2549	3.4	.08
OC × ID_{Glob}	11220	2551	4.4	.05
OC × ID_{Loc}	1255	1351	0.9	.35
Task × OC	17911	2451	7.3	.01[d]
ID_{Glob} × ID_{Loc}	934812	20471	45.7	.01
Task × ID_{Glob}	6381	15143	0.4	.52
Task × ID_{Loc}	2438	3518	0.7	.42
OC × GSize × Ord_B	6016	1171	5.1	.04
GSize × ID_{Glob} × Ord_B	873	3324	0.3	.61
GSize × ID_{Loc} × Ord_B	9580	1662	5.8	.03
Task × GSize × Ord_B	11687	2549	4.6	.05
OC × ID_{Glob} × Ord_B	524	2551	0.2	.66
OC × ID_{Loc} × Ord_B	511	1351	0.4	.55
Task × OC × Ord_B	99	2451	0.1	.84
ID_{Glob} × ID_{Loc} × Ord_B	2560	20471	0.1	.73
Task × ID_{Glob} × Ord_B	1932	15143	0.1	.73
Task × ID_{Loc} × Ord_B	4	3518	0.1	.97
OC × GSize × ID_{Glob}	54	4640	0.1	.92
OC × GSize × ID_{Loc}	653	1945	0.3	.57
Task × OC × GSize	175	4030	0.1	.84
GSize × ID_{Glob} × ID_{Loc}	11231	4267	2.6	.12
Task × GSize × ID_{Glob}	3384	2402	1.4	.25
Task × GSize × ID_{Loc}	787	4683	0.2	.69
OC × ID_{Glob} × ID_{Loc}	5589	4470	1.3	.28
Task × OC × ID_{Glob}	15809	3135	5.0	.04[e]
Task × ORG × ID_{Loc}	3883	2080	1.9	.19
Task × ID_{Glob} × ID_{Loc}	274963	7334	37.5	.01
OC × GSize × ID_{Glob} × Ord_B	4	4640	0.1	.98
OC × GSize × ID_{Loc} × Ord_B	3906	1945	2.0	.17
Task × OC × GSize × Ord_B	575	4030	0.1	.71
Task × GSize × ID_{Glob} × Ord_B	720	2402	0.3	.59
GSize × ID_{Glob} × ID_{Loc} × Ord_B	111	4267	0.1	.87
Task × GSize × ID_{Loc} × Ord_B	21	4683	0.1	.95
OC × ID_{Glob} × ID_{Loc} × Ord_B	1658	4470	0.4	.55
Task × OC × ID_{Glob} × Ord_B	1350	3135	0.4	.52
Task × OC × ID_{Loc} × Ord_B	449	2080	0.2	.65
Task × ID_{Glob} × ID_{Loc} × Ord_B	8253	7334	1.1	.30
OC × GSize × ID_{Glob} × ID_{Loc}	773	3545	0.2	.65
Task × OC × GSize × ID_{Glob}	491	1915	0.3	.62
Task × OC × GSize × ID_{Loc}	889	1614	0.6	.47
Task × GSize × ID_{Glob} × ID_{Loc}	2826	2053	1.4	.26
Task × OC × ID_{Glob} × ID_{Loc}	3379	1772	1.9	.18
OC × GSize × ID_{Glob} × ID_{Loc} × Ord_B	772	3545	0.2	.65
Task × OC × GSize × ID_{Loc} × Ord_B	279	1614	0.2	.68
Task × OC × GSize × ID_{Glob} × Ord_B	1407	1915	0.7	.40

(*Appendices continue*)

Table A5 (*continued*)

Source[b,c]	MS_{effect}	MS_{error}	F	p
Task × GSize × ID_{Glob} × ID_{Loc} × Ord_B	1925	2053	0.9	.35
Task × OC × ID_{Glob} × ID_{Loc} × Ord_B	241	1772	0.1	.72
Task × OC × GSize × ID_{Glob} × ID_{Loc}	5347	3098	1.7	.21
Task × OC × GSize × ID_{Glob} × ID_{Loc} × Ord_B	2340	3098	0.8	.40

[a] Only interactions involving Local Task Type (detection vs. identification) and Organizational Complexity are of potential theoretical interest in this analysis. [b] Task = Local Task Type (detection vs. identification); OC = Organizational Complexity (2-level vs. 3-level); GSize = Global Size (large vs. small); ID_{Glob} = Global-letter Identity (H vs. S); ID_{Loc} = Local-letter Identity (H vs. S); Ord_B = Local-task Block Order (detection then identification vs. identification then detection). [c] $df_{effect} = 1$ and $df_{error} = 18$ for the entire analysis. [d] Two-way interaction reflecting a significant effect of organizational complexity (slower overall RT for 3-level than 2-level stimuli)in the identification task, but not in the detection task (see Experiment 2 for discussion). [e] Three-way interaction reflecting a significant two-way interaction between organizational complexity and global-letter identity in the identification task only, whereby the effect of organizational complexity (slower overall RT for 3-level than 2-level stimuli) was statistically significant when the global letter was an S, but not when it was an H.

Table A6
Six-Way ANOVA on Experiment 3 RT Data

Source[a,b]	MS_{effect}	MS_{error}	F	p
Ord_B	2229411	447213	5.0	.04
GSize	48103	3127	15.4	.01
OC	16793	2957	5.7	.03
ID_{Glob}	26370	2267	11.6	.01
ID_{Loc}	9139	6532	1.4	.26
Ord_{ID}	5400	74456	0.1	.79
OC × Ord_B	3852	2957	1.3	.27
ID_{Glob} × Ord_B	136	2267	0.1	.81
ID_{Loc} × Ord_B	12842	6532	2.0	.18
Ord_{ID} × Ord_B	249593	74456	3.4	.09
OC × GSize	4117	1643	2.5	.14
GSize × ID_{Glob}	9431	963	9.8	.01[c]
GSize × ID_{Loc}	648	1588	0.4	.53
GSize × Ord_B	974	3127	0.3	.59
Ord_{ID} × GSize	24581	2261	10.9	.01[d]
OC × ID_{Glob}	97	2315	0.1	.84
OC × ID_{Loc}	1490	1925	0.8	.39
Ord_{ID} × OC	4513	2953	1.5	.24
ID_{Glob} × ID_{Loc}	1608784	44299	36.3	.01
Ord_{ID} × ID_{Glob}	322	10802	0.1	.87
Ord_{ID} × ID_{Loc}	2333	6180	0.4	.55
OC × GSize × Ord_B	1428	1643	0.9	.37
GSize × ID_{Glob} × Ord_B	61	963	0.1	.80
GSize × ID_{Loc} × Ord_B	1	1588	0.1	.99
Ord_{ID} × GSize × Ord_B	241	2261	0.1	.75
OC × ID_{Glob} × Ord_B	682	2315	0.3	.60
OC × ID_{Loc} × Ord_B	1812	1925	0.9	.35
Ord_{ID} × OC × Ord_B	341	2953	0.1	.74
ID_{Glob} × ID_{Loc} × Ord_B	70325	44299	1.6	.23
Ord_{ID} × ID_{Glob} × Ord_B	7303	10802	0.7	.42
Ord_{ID} × ID_{Loc} × Ord_B	2453	6180	0.4	.54
OC × GSize × ID_{Glob}	3432	1152	3.0	.11
OC × GSize × ID_{Loc}	2039	1989	1.0	.33
Ord_{ID} × OC × GSize	165	2586	0.1	.80
GSize × ID_{Glob} × ID_{Loc}	1	1287	0.1	.99
Ord_{ID} × GSize × ID_{Glob}	9	2213	0.1	.95
Ord_{ID} × GSize × ID_{Loc}	4005	2282	1.8	.21
OC × ID_{Glob} × ID_{Loc}	4329	3018	1.4	.25

(*Appendices continue*)

Table A6 (*continued*)

Source[a,b]	MS_{effect}	MS_{error}	F	p
$Ord_{ID} \times OC \times ID_{Glob}$	82	1534	0.1	.82
$Ord_{ID} \times OC \times ID_{Loc}$	2269	1391	1.6	.22
$Ord_{ID} \times ID_{Glob} \times ID_{Loc}$	1027	7502	0.1	.72
$OC \times GSize \times ID_{Glob} \times Ord_{B}$	181	1152	0.2	.70
$OC \times GSize \times ID_{Loc} \times Ord_{B}$	1063	1989	0.5	.48
$Ord_{ID} \times OC \times GSize \times Ord_{B}$	260	2586	0.1	.76
$Ord_{ID} \times GSize \times ID_{Glob} \times Ord_{B}$	560	2213	0.3	.62
$GSize \times ID_{Glob} \times ID_{Loc} \times Ord_{B}$	1103	1287	0.9	.37
$Ord_{ID} \times GSize \times ID_{Loc} \times Ord_{B}$	568	2282	0.2	.63
$OC \times ID_{Glob} \times ID_{Loc} \times Ord_{B}$	363	3018	0.1	.73
$Ord_{ID} \times OC \times ID_{Glob} \times Ord_{B}$	993	1534	0.6	.43
$Ord_{ID} \times OC \times ID_{Loc} \times Ord_{B}$	857	1391	0.6	.45
$Ord_{ID} \times ID_{Glob} \times ID_{Loc} \times Ord_{B}$	5504	7502	0.7	.41
$OC \times GSize \times ID_{Glob} \times ID_{Loc}$	194	1848	0.1	.75
$Ord_{ID} \times OC \times GSize \times ID_{Glob}$	35	2460	0.1	.91
$Ord_{ID} \times OC \times GSize \times ID_{Loc}$	579	1650	0.4	.56
$Ord_{ID} \times GSize \times ID_{Glob} \times ID_{Loc}$	35	2958	0.1	.91
$Ord_{ID} \times OC \times ID_{Glob} \times ID_{Loc}$	345	1719	0.2	.66
$OC \times GSize \times ID_{Glob} \times ID_{Loc} \times Ord_{B}$	19	1848	0.1	.92
$Ord_{ID} \times OC \times GSize \times ID_{Glob} \times Ord_{B}$	965	2460	0.4	.54
$Ord_{ID} \times OC \times GSize \times ID_{Loc} \times Ord_{B}$	4035	1650	2.4	.14
$Ord_{ID} \times OC \times GSize \times ID_{Glob} \times ID_{Loc}$	4785	3865	1.2	.28
$Ord_{ID} \times OC \times ID_{Glob} \times ID_{Loc} \times Ord_{B}$	117	1719	0.1	.80
$Ord_{ID} \times GSize \times ID_{Glob} \times ID_{Loc} \times Ord_{B}$	273	2958	0.1	.77
$Ord_{ID} \times OC \times GSize \times ID_{Glob} \times Ord_{B} \times ID_{Loc}$	3353	3865	0.9	.37

[a] Ord_{ID} = Identification Order (global-local vs. local-global); OC = Organizational Complexity (2-level vs. 3-level); GSize = Global Size (large vs. small); ID_{Glob} = Global-letter Identity (H vs. S); ID_{Loc} = Local-letter Identity (H vs. S); Ord_{B} = Identification-order Block Order (global-local then local-global vs. local-global then global-local). [b] $df_{effect} = 1$ and $df_{error} = 14$ for the entire analysis. [c] Two-way interaction reflecting a significant global size effect (slower overall RT for larger than smaller global stimuli) when the global letter is S, with the effect only approaching significance when the global letter is H. [d] Two-way interaction reflecting a significant global size effect (slower overall RT for larger than smaller global stimuli) when the identification order is global-local (focusing), but not when the identification order is local-global (defocusing; see Experiment 3 for discussion).

Table A7
Six-Way ANOVA on Pretest RT Data (See Appendix I)

Source[a,b]	MS_{effect}	MS_{error}	F	p
Level	108805	18854	5.7	.03
GSize	8363	18000	0.4	.51
OC	33	1298	0.2	.87
ID_{Glob}	24092	4315	5.5	.03
ID_{Loc}	50258	4432	11.3	.01
Ord_{B}	94962	344986	0.3	.61
Level $\times$ GSize	39012	2806	10.3	.01[c]
Level $\times$ OC	8449	2806	3.0	.10
Level $\times$ ID_{Glob}	23780	3491	6.8	.02
Level $\times$ ID_{Loc}	436	2434	0.1	.68
Level $\times$ Ord_{B}	753	18854	0.4	.84
GSize $\times$ OC	3722	1758	2.1	.16
GSize $\times$ ID_{Glob}	2014	1916	1.0	.32
GSize $\times$ ID_{Loc}	8494	1425	5.9	.03[d]
GSize $\times$ Ord_{B}	14753	18000	0.8	.38
OC $\times$ ID_{Glob}	85	1913	0.1	.84
OC $\times$ ID_{Loc}	5710	3558	1.6	.22
OC $\times$ Ord_{B}	1011	1298	0.7	.39

(*Appendices continue*)

Table A7 (*continued*)

Source[a,b]	MS_{effect}	MS_{error}	F	p
$ID_{Glob} \times ID_{Loc}$	39734	2169	18.3	.01
$ID_{Glob} \times Ord_B$	656	4315	0.1	.70
$ID_{Loc} \times Ord_B$	11891	4432	2.6	.12
Level × GSize × OC	3.183	3062	0.1	.98
Level × GSize × ID_{Glob}	3976	2702	1.4	.24
Level × GSize × ID_{Loc}	95	2888	0.1	.86
Level × GSize × Ord_B	684	3797	0.1	.68
Level × OC × ID_{Glob}	407	2387	0.1	.69
Level × OC × ID_{Loc}	6078	1798	3.3	.08
Level × OC × Ord_B	2495	2806	0.8	.36
Level × $ID_{Glob} \times ID_{Loc}$	3178	1591	1.9	.18
Level × $ID_{Glob} \times Ord_B$	817	3491	0.2	.64
Level × $ID_{Loc} \times Ord_B$	1540	2434	0.6	.44
GSize × OC × ID_{Glob}	76	2616	0.1	.87
GSize × OC × ID_{Loc}	4804	2603	1.8	.19
GSize × OC × Ord_B	792	1758	0.4	.51
GSize × $ID_{Glob} \times ID_{Loc}$	2495	1280	1.9	.18
GSize × $ID_{Glob} \times Ord_B$	1267	1916	0.6	.43
GSize × $ID_{Loc} \times Ord_B$	1527	1425	1.0	.32
OC × $ID_{Glob} \times ID_{Loc}$	328	1300	0.2	.62
OC × $ID_{Glob} \times Ord_B$	3435	1913	1.7	.20
OC × $ID_{Loc} \times Ord_B$	776	3558	0.2	.65
$ID_{Glob} \times ID_{Loc} \times Ord_B$	229	2169	0.1	.75
Level × GSize × OC × ID_{Glob}	176	2811	0.1	.81
Level × GSize × OC × ID_{Loc}	4472	2180	2.0	.17
Level × GSize × OC × Ord_B	54	3062	0.1	.90
Level × GSize × $ID_{Glob} \times Ord_B$	27	2702	0.1	.92
Level × GSize × $ID_{Glob} \times ID_{Loc}$	1472	2811	0.5	.48
Level × GSize × $ID_{Loc} \times Ord_B$	55	2888	0.1	.89
Level × OC × $ID_{Glob} \times ID_{Loc}$	4273	1076	3.9	.06[e]
Level × OC × $ID_{Glob} \times Ord_B$	3105	2387	1.3	.27
Level × OC × $ID_{Loc} \times Ord_B$	95	1798	0.5	.82
Level × $ID_{Glob} \times ID_{Loc} \times Ord_B$	5345	1591	3.3	.08
GSize × OC × $ID_{Glob} \times ID_{Loc}$	1195	1168	1.0	.33
GSize × OC × $ID_{Glob} \times Ord_B$	1	2616	0.1	.99
GSize × OC × $ID_{Loc} \times Ord_B$	6860	2603	2.6	.12
GSize × $ID_{Glob} \times ID_{Loc} \times Ord_B$	8	1280	0.1	.94
OC × $ID_{Glob} \times ID_{Loc} \times Ord_B$	5448	1300	4.1	.06[f]
Level × GSize × OC × $ID_{Glob} \times ID_{Loc}$	414	1474	0.2	.60
Level × GSize × OC × $ID_{Glob} \times Ord_B$	170	2811	0.1	.81
Level × GSize × OC × $ID_{Loc} \times Ord_B$	131	2180	0.1	.81
Level × GSize × $ID_{Glob} \times ID_{Loc} \times Ord_B$	1911	2811	0.6	.42
Level × OC × $ID_{Glob} \times ID_{Loc} \times Ord_B$	596	1076	0.5	.47
GSize × OC × $ID_{Glob} \times ID_{Loc} \times Ord_B$	1356	1168	1.1	.30
Level × OC × GSize × $ID_{Glob} \times ID_{Loc} \times Ord_B$	59	1474	0.1	.84

[a] Level = Target Level (global vs. local); OC = Organizational Complexity (2-level vs. 3-level); GSize = Global Size (large vs. small); ID_{Glob} = Global-letter Identity (H vs. S); ID_{Loc} = Local-letter Identity (H vs. S); Ord_B = Target-level Block Order (global then local vs. local then global). [b] $df_{effect} = 1$ and $df_{error} = 17$ for the entire analysis. [c] Two-way interaction reflecting a nonsignificant trend toward faster identification of larger than smaller global stimuli, with no such trend for local-level identification (see Appendix I). [d] Two-way interaction reflecting a nonsignificant difference of faster identification responses in large compared to small global stimuli composed of local S elements, with an equal performance for stimuli composed of local H elements. [e] Four-way interaction reflecting one significant simple effect of organizational complexity (faster identification of the global level of 3-level compared to 2-level stimuli when the global level is H and the local level is S), with nonsignificant simple effects in all of the other seven combinations of target level × global-letter identity × local-letter identity. [f] Four-way interaction reflecting one significant simple effect of organizational complexity (faster identification of targets in 3-level compared to 2-level stimuli when the global level identification block preceded the local level identification block and both the global and local level letters are S), with nonsignificant simple effects in all of the other seven combinations of target-level block order × global-letter identity × local-letter identity.

(*Appendices continue*)

Table A8

Five-Way ANOVA on the Combined RT Data for the 2-Level Stimuli in the Dynamic Focusing Task of Experiment 1 and the Follow-Up Experiment (See Appendix II)

Source[a,b]	MS_{effect}	MS_{error}	F	p
Ord_B	994653	419136	2.4	.13
GSize	18073	4284	4.2	.05
ID_{Glob}	245646	10299	23.9	.01
ID_{Loc}	88590	12829	6.9	.01
Ord_{ID}	22075	24980	0.9	.35
$ID_{Glob} \times Ord_B$	5965	10299	0.6	.45
$ID_{Loc} \times Ord_B$	75	12829	0.1	.94
$Ord_{ID} \times Ord_B$	23224	24980	0.9	.34
GSize $\times ID_{Glob}$	2123	1743	1.2	.28
GSize $\times ID_{Loc}$	2203	2843	0.8	.38
GSize $\times Ord_B$	25028	4284	5.8	.02[c]
$Ord_{ID} \times$ GSize	4639	3186	1.5	.24
$ID_{Glob} \times ID_{Loc}$	3835234	17765	215.9	.01
$Ord_{ID} \times ID_{Glob}$	4184	7346	0.6	.46
$Ord_{ID} \times ID_{Loc}$	6285	3635	1.7	.20
GSize $\times ID_{Glob} \times Ord_B$	443	1743	0.3	.62
GSize $\times ID_{Loc} \times Ord_B$	163	2843	0.1	.81
$Ord_{ID} \times$ GSize $\times Ord_B$	12582	3186	3.9	.06[d]
$ID_{Glob} \times ID_{Loc} \times Ord_B$	3952	17765	0.2	.64
$Ord_{ID} \times ID_{Glob} \times Ord_B$	8364	7346	1.1	.29
$Ord_{ID} \times ID_{Loc} \times Ord_B$	2303	3635	0.6	.43
GSize $\times ID_{Glob} \times ID_{Loc}$	543	5298	0.1	.75
$Ord_{ID} \times$ GSize $\times ID_{Glob}$	1859	3215	0.6	.45
$Ord_{ID} \times$ GSize $\times ID_{Loc}$	2652	2231	1.2	.28
$Ord_{ID} \times ID_{Glob} \times ID_{Loc}$	3526	7776	0.5	.51
$Ord_{ID} \times$ GSize $\times ID_{Glob} \times Ord_B$	21459	3215	6.7	.01[e]
GSize $\times ID_{Glob} \times ID_{Loc} \times Ord_B$	3429	5298	0.6	.43
$Ord_{ID} \times$ GSize $\times ID_{Loc} \times Ord_B$	3626	2231	1.6	.21
$Ord_{ID} \times ID_{Glob} \times ID_{Loc} \times Ord_B$	4630	7776	0.6	.45
$Ord_{ID} \times$ GSize $\times ID_{Glob} \times ID_{Loc}$	681	5599	0.1	.73
$Ord_{ID} \times$ GSize $\times ID_{Glob} \times ID_{Loc} \times Ord_B$	708	5599	0.1	.72

[a] Ord_{ID} = Identification Order (global-local vs. local-global); GSize = Global Size (large vs. small); ID_{Glob} = Global-letter Identity (H vs. S); ID_{Loc} = Local-letter Identity (H vs. S); Ord_B = Identification-order Block Order (global-local then local-global vs. local-global then global-local). [b] $df_{effect} = 1$ and $df_{error} = 34$ for the entire analysis. [c] Two-way interaction qualified by a higher-order interaction (see note *e*, following). [d] Three-way interaction qualified by higher-order interaction (see note *e*, following). [e] Four-way interaction reflecting significant simple effects of global size (slower overall RT for larger than smaller global stimuli) when the local-global (defocusing) block preceded the global-local (focusing) block, in all cases except when the identification order is global-local and the global letter is H; all simple effects of global size in the opposite block order were nonsignificant.

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