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# Primacy of Wholistic Processing and Global/Local Paradigm: A Critical Review

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The question of whether perception is analytic or wholistic is an enduring issue in psychology. The global-precedence hypothesis, considered by many as a modern version of the Gestaltist claim about the perceptual primacy of wholes, has generated a large body of research, but the debate still remains very active. This article reviews the research within the global/local paradigm, and critically analyzes the assumptions underlying this paradigm. The extent to which this line of research contributes to understanding the role of wholistic processing in object perception is discussed. It is concluded that one should be very cautious in making inferences about wholistic processing from the processing advantage of the global level of stimulus structure. A distinction is proposed between global properties, defined by their position in the hierarchical structure of the stimulus, and wholistic properties, defined as a function of interrelations among component parts. It is suggested that a direct comparison between processing of wholistic and component properties is needed to support the hypothesis about the perceptual primacy of wholistic processing.

> Marco Polo describes a bridge, stone by stone.
> "But which is the stone that supports the bridge?" Kublai Khan asks.
> "The bridge is not supported by one stone or another," Marco answers, "but by the line of the arch that they form."
> Kublai Khan remains silent, reflecting. Then he adds: "Why do you speak to me of stones? It is only the arch that matters to me."
> Polo answers: "Without stones there is no arch." (Italo Calvino, 1972/1974, p. 82)

One of the most enduring issues in the psychology of perception concerns the perceptual relations between wholes and their parts. The question is whether processing of the overall structure precedes and determines the processing of the component parts or properties or whether the parts are registered first and are then synthesized to form the objects of our awareness. This question permeates many topics in psychology, theoretical and applied. To mention just a few examples: Does one recognize faces by identifying facial features, such as eyes, nose, mouth, or by perceiving the overall configuration first? (see, e.g., Bruce, 1988); does one form conceptual categories by detecting defining features or by apprehension of family resemblance? (see, e.g., Rosch, 1978); which is the better method of teaching reading, the whole word method or the letter-by-letter (phonic) method? (see, e.g., Rayner & Pollatsek, 1989); and can perceptual/cognitive development be characterized by a trend from a wholistic to an analytic mode? (see, e.g., Kemler, 1983; Werner, 1948). This article concentrates on direct experimental treatment of the wholistic primacy issue and on relevant conceptual problems; nonetheless, it also bears on the aforementioned topics and many others.

Two basic positions on this issue can be traced back to the controversy between two schools of perceptual thought: structuralism and Gestalt. The structuralists (e.g., Titchener, 1909; Wundt, 1874) were rooted firmly in British empiricism, with its emphasis on atomism and associative mechanisms, and were also influenced by 19th-century physiology. They held that the basic units of perception are independent local sensations and their physiological counterparts, specific nerve energies. In their view, every sensory whole must be built up from a conglomerate of elementary sensations, and the perception of segregated, organized units corresponding to objects in the physical world is achieved only by associations learned through experience.

The Gestaltists (e.g., Koffka, 1935/1963; Kohler, 1929, 1930/1971; Wertheimer, 1925/1967), on the other hand, argued against both the atomistic assumption and the role of learning in perception, asserting the primacy of whole units and organization in the percept. A basic tenet of the Gestalt view is that a specific sensory whole is qualitatively different from the complex that one might predict by considering only its parts. The whole quality is not just one more added element or factor, as was proposed by Ehrenfels's (1890) *Gestaltqualität,* nor does it "arise (through the agency of any auxiliary factor) as a secondary process from the sum of the pieces as such. Instead, what takes place in each single part already depends upon what the whole is" (Wertheimer, 1925/1967, p. 5). Thus, the quality of a part is determined by the whole in which this part is integrated. According to the Gestalt theory, the perception of distinct organized units is not the product of sensory elements tied together by associative learning but is, instead, an immediate product of electrical field processes in the brain that respond to the entire pattern of stimulation.

The basic flavor of the structuralist approach has been re-

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tained in many current models of perception, especially models of pattern and object recognition (see Treisman, 1986, for an extensive review). Such analytic models assume that objects are identified, recognized, and classified by detecting combinations of elementary features.

In the last 15 years or so, the Gestaltist view of perception (excluding their physiological theory) has recaptured the interest of cognitive psychologists (e.g., Beck, 1982; Boff, Kaufman, & Thomas, 1986, Vol. 2; Gopher & Kimchi, 1989; Kubovy & Pomerantz, 1981; Shepp & Ballesteros, 1989). This revival includes work on such issues as perceptual grouping, global/local processing, object-superiority effects, configural-superiority effects, texture discrimination, and event perception. It is also expressed in the growing usage of the term *wholistic* rather than *analytic* to describe perception (e.g., Uttal, 1988).

There has been much confusion regarding the notion of *wholistic* perception, in part because of the looseness with which the term is used in the literature, often without a clear theoretical or operational definition. One issue regarding terminology needs to be clarified at the outset. The distinction between wholistic versus analytic processing is sometimes referred to as a distinction between top-down versus bottom-up processing (e.g., Kinchla, Solis-Macias, & Hoffman, 1983; Kinchla & Wolfe, 1979). However, the terms *top-down* and *bottom-up* processing are often used to refer to the distinction between conceptually driven processing on the one hand and data-driven processing on the other (e.g., Lindsey & Norman, 1977; Rumelhart, 1977). The issue of wholistic/analytic processing is orthogonal to this latter usage of the terms *top-down* and *bottom-up.* Whether the processing of the stimulus starts with the sensory information (i.e., bottom-up, data-driven processing) or with an internal hypothesis that guides processing (i.e., top-down, conceptually driven processing) does not necessarily imply which stimulus aspects will be processed first (see also Kimchi, 1982/1983; Navon, 1981b; Pomerantz, 1981; Treisman, 1986). For the sake of clarity it seems best to save the terms *top-down* and *bottom-up* processing to refer only to conceptually driven and data-driven processing, respectively.

## What Is Wholistic Processing?

There are, in fact, at least two different usages of the term *wholistic* processing. The first, which is considered to be more in the spirit of the Gestalt theory, refers to the primacy of wholistic properties in perception. In this usage, the terms *wholistic* and *global* are often used interchangeably to express the hypothesis that the initial information-processing step in the identification, discrimination, or classification of objects involves processing of wholistic properties rather than component properties (e.g., Navon, 1977, 1981b; Uttal, 1988).[1]

The other usage refers to the notion that the unitary whole, rather than its properties (whether wholistic or component), is the primary unit for processing. To get some intuition about unitary wholes, consider the phenomenon of having the impression that two faces are similar without noticing the color of the eyes or the shape of the nose. This and other similar phenomena have led several investigators to hypothesize a propertyless representation (e.g., J. D. Smith, 1989). In its strong version, such a notion seems to entail that at some level of processing, properties as such have no immediate psychological reality. Note that from this point of view, the primacy of wholistic properties suggested by the other usage would be considered analytic processing, because properties (though wholistic ones) would have a definite psychological reality. The unitary whole sense of wholistic processing is most often used by investigators working on dimensional interaction, in particular with regard to the distinction between integral and separable dimensions (e.g., Lockhead, 1972; Garner, 1974; Kemler Nelson, 1989; Shepp, 1989). Some of the confusion regarding the unitary whole notion of wholistic processing is due to the tendency to equate the wholistic/analytic distinction with the integrality/separability one. Integrality and separability refer to types of stimulus structure that place constraints on possible modes of processing such as wholistic or analytic. If, however, wholistic mode of processing is defined simply as the processing of integral stimuli (e.g., Ballesteros, 1989), not only is it somewhat circular but also it becomes unclear what remains to be accounted for by wholistic processing that is not already accounted for by the stimulus structure itself. Wholistic processing may be mandatory or primary for a certain type of stimulus structure, such as integral structure (Garner, 1974), but it is not to be equated with it. Rather, a mode of processing (analytic or wholistic) can be identified by the convergence of performance characteristics *across* stimuli for given information-processing tasks (see Garner, 1974; Kimchi & Goldsmith, in press). For example, a wholistic mode of processing in high-speed classification tasks has been inferred from classification performance that is based on overall similarity relations across both integral and separable stimuli (Foard & Kemler Nelson, 1984; J. D. Smith & Kemler Nelson, 1984). A very thoughtful attempt to explicate this notion of wholistic processing can be found in Kemler Nelson (1989), and I refer the reader to it for further information.

In this article I focus on the former sense of wholistic processing, which refers to the primacy of wholistic properties. A visual object, viewed as a whole, has both wholistic properties and component properties/parts. Wholistic properties are properties that depend on the interrelations between the component parts (e.g., Garner, 1978; Navon, 1977; Rock, 1986). The Gestaltist claim that the whole is more or at least different from the sum of its parts can perhaps be captured by the notion of wholistic properties such as closure, symmetry, and certain other spatial relations between the component parts. Such properties do not inhere in the component parts and cannot be predicted by considering only the component parts. Within this conceptualization, the global-precedence hypothesis, put forward by Navon (1977), is considered by many cognitive psychologists to be a modern version of the Gestaltists' claim about the primacy of wholistic or global processing in perception (e.g., Pomerantz, 1981; Robertson, 1986; Treisman, 1986;

[1] A more common expression of this hypothesis is that the whole is perceived before its parts. This is however a loose way to put it because the whole contains the parts. The question is, rather, whether properties of the whole that do not inhere in the parts but are instead a function of the interrelations between the parts (i.e., wholistic properties) are perceived before the parts.

Uttal, 1988). This hypothesis has generated a wealth of empirical research, which has nonetheless left the issue still unsettled and somewhat confused.

I first present the hypothesis along with the framework in which it was formulated and the experimental paradigm used to test it. I then review the research within this paradigm, critically analyze some basic assumptions underlying much of this research, and examine the extent to which this line of research has been able to shed light on the primacy of wholistic properties.

## Global/Local Processing

### *Global-Precedence Hypothesis*

Posing the question "Is the perceptual whole literally constructed out of the percepts of its elements?" (p. 353), Navon (1977) proposed that "perceptual processes are temporally organized so that they proceed from global structuring towards more and more fine-grained analysis. In other words, a scene is decomposed rather than built up" (Navon, 1977, p. 354).

To fully grasp the global-precedence hypothesis requires an understanding of the framework within which it was formulated. A visual scene can be viewed as a hierarchical network of subscenes interrelated by spatial relationships (e.g., Palmer, 1977; Winston, 1975). The globality of a visual property corresponds to the place it occupies in the hierarchy: Properties at the top of the hierarchy are more global than those at the bottom, which in turn are more local. Consider for example the structure of a human face. The face as a whole has global properties (e.g., shape, expression) as well as a set of local properties, or component parts (e.g., eyes, nose, dimples). In turn, the component parts when considered as wholes also have global properties and a further set of local properties. The global-precedence hypothesis claims that the processing of a scene is global to local. That is, global properties of a visual object are processed first, followed by analysis of local properties.

This hypothesis has been tested in the elegant global/local paradigm by studying the perception of hierarchically constructed patterns, in which larger figures are constructed by suitable arrangement of smaller figures. An example is a set of large letters constructed from the same set of smaller letters (see Figure 1). Hereafter I sometimes use *global configuration* to refer to the larger figure and *local elements* to refer to the smaller figures.

```
H       H     S       S
H       H     S       S
H       H     S       S
H H H H H     S S S S S
H       H     S       S
H       H     S       S
H       H     S       S

  H H H         S S S
H       H     S       S
H             S
H H H H H     S S S S S
        H             S
H       H     S       S
  H H H         S S S
```

*Figure 1.* Examples of the compound letters used in the global/local paradigm.

The choice of hierarchical patterns for testing the global-to-local hypothesis is seemingly well motivated, and the rationale is as follows: The larger figure and the smaller figure can be equally complex, recognizable, and codable, and one cannot be predicted from the identity of the other. Once they are equated, except for their level of globality, performance measures such as relative speed of identification and/or asymmetric interference can be used to infer the precedence of one level or the other (Navon, 1977, 1981b).

The local elements of hierarchical patterns are not, and were not meant to be, the local properties of the larger figure. For example, the local properties of the letter *H*, are, among others, vertical and horizontal lines, in much the same way as eyes, nose, and mouth are local properties of a face (e.g., Kimchi, 1982/1983; McLean, 1978/1979; Navon, 1981b). The larger and the smaller figures of hierarchical patterns are levels of pattern structure, each is assumed to be a stimulus on its own right. They differ in their level of globality. The larger letter is considered a higher level unit in relation to the smaller letters, which are, in turn, lower level units. Properties of the higher level unit are considered to be more global than properties of the lower level units by virtue of their position in the hierarchy. Thus, the use of hierarchical patterns is an attempt to give an operational definition of level of globality in terms of levels of stimulus structure. (Whether the two levels of pattern structure map directly into two perceptual levels that differ in their level of globality is in fact crucial for the global/local paradigm, and I discuss it in detail later.) Given this operational definition of globality/locality, the global-to-local hypothesis that is actually tested by hierarchical patterns is the following: *The properties of a higher level unit are processed first, followed by analysis of the properties of the lower level units* (Kimchi, 1982/1983; Navon, 1981b; Ward, 1982).

By a set of converging operations, Navon (1977) demonstrated the advantage of global configurations. In two experiments (Navon, 1977, Experiments 1 & 2), he asked subjects to respond to an auditorily presented name of a letter while looking at a hierarchical letter. The subject's auditory discrimination responses were affected (interfered or facilitated) by the global level of the visual stimuli but not by the local one. In another experiment (Navon, 1977, Experiment 3), Navon used a Stroop-like interference task and found that conflicting information between the local and the global levels (e.g., a large *H* made up of small *S*s) had an inhibitory influence on identification of the local letter but not on the identification of the global letter. Navon interpreted these findings as evidence for the inevitability of global precedence in visual perception.

At this point, I will clarify a number of issues regarding the global-precedence hypothesis, which are relevant to the research within the global/local paradigm.

First, note that the global-precedence hypothesis is a hypothesis about the development of the percept. It claims that global properties have temporal precedence during the microgenesis of the percept. It does not necessarily imply what is salient in the final percept (Navon, 1977, 1981b). Global-to-local interference and faster responses to the global structure are, on the other hand, empirical findings indicating global advantage or superiority. Such advantage effects suggest the processing dominance of the global structure. Processing dominance, however, can have a number of causes, at different stages of processing, only one of which can be the temporal precedence of the global structure. Thus, global precedence is a theoretical account of the phenomenon of global advantage and should not be confused with it (see also Kimchi, 1982/1983; Navon, 1981b; Ward, 1983). As we see later, many of the studies within the global/local paradigm examined the generality of the phenomenon, demonstrating the conditions under which global or local advantage is to be observed. Not all of them, however, speak directly to the precedence hypothesis, because they may tap different stages of processing. In keeping with these notions, hereafter, I use the term (global/local) *precedence* to refer to the theoretical hypothesis and the terms (global/local) *advantage* or *superiority* to refer to the empirical findings.

Second, the global-precedence hypothesis, at least as originally presented by Navon, does not refer to a distinction between stages of attention (i.e., preattentive vs. attentive). Rather, it is "a claim about perceptual analysis of whatever is *attended to*" (Navon, 1977, p. 355). Nonetheless, it has been interpreted by some researchers (e.g., Broadbent, 1977; Paquet & Merikle, 1988; Uttal, 1988) as a hypothesis about preattentive processing, similar to Neisser's (1967) suggestion that pattern processing begins with preattentive, crude, and "global" analysis.

Third, the original hypothesis (Navon, 1977) assumed a serial processing: Processing resources are first engaged with global information, and processing of local information is optional. Later, Navon (1981b) suggested the possibility of parallel processing of global and local information, with the global information being processed faster and thus being available earlier than the local one.

Quite a number of researchers have used similar stimuli (i.e., hierarchical letters composed of many small letters) and used identical or similar experimental tasks (e.g., Stroop-like task, target search, speeded classification) to explore the generality of global advantage, its source, or its locus. These studies demonstrated important boundary conditions of the phenomenon and pointed out certain variables that can affect global versus local superiority. I turn now to a detailed review of these studies.

### *Factors Affecting Global Advantage*

*Overall visual angle.* Kinchla and Wolfe (1979) addressed the question whether global advantage is due to differences between targets of different size. Using a target search paradigm in which subjects had to search for a designated target either at the global or the local level of hierarchical patterns, Kinchla and Wolfe varied the overall visual angle of the patterns by randomly presenting patterns ranging in size from 4.8° to 22.1° of visual angle. They found a global advantage in reaction time with patterns subtending less than about 7° of visual angle, but they found a local advantage with larger patterns. Using a paradigm similar to the one used by Navon (1977), McLean (1978/1979) found that global advantage did not hold for patterns larger than about 10° of visual angle. Kinchla and Wolfe suggested that the perceptual system favors stimuli of a certain fixed size and those are processed first, then larger or smaller stimuli are processed. Lamb and Robertson (1990) showed, however, that the transition from a global to a local reaction-time advantage depends on which visual angles are included in the stimulus set.

Navon and Norman (1983) claimed that in the studies mentioned above globality was confounded with eccentricity (i.e., distance from the fovea). In the typical hierarchical letters, the global letter is farther from the fovea than some of the local letters, so that the local letter can benefit from greater acuity. To avoid this confound, Navon and Norman used stimuli with all their elements located along their perimeter (Cs & Os; see Figure 2) and found a global advantage for both small (2°) and large (17.25°) visual angles. These results suggest that over a wide range of visual angles, global advantage is obtained, provided that eccentricity is held constant.

*Retinal location (foveal vs. peripheral).* Pomerantz (1983) and Grice, Canham, and Boroughs (1983) showed that retinal location can affect the relative speed of processing of global and local levels: A global advantage was obtained with peripheral presentation, but no global advantage was obtained with central presentation. Pomerantz (1983) and Grice et al. (1983) interpreted their findings as suggesting that global advantage results from a decrease in acuity with distance from the fovea, which affects small letters more than large letters. Two alternative accounts for their findings need to be considered. First, retinal location was confounded with spatial uncertainty: Central presentations were fixed, but the location of the peripheral presentations was uncertain. It is possible, then, that spatial uncertainty rather than retinal location may account for their find-

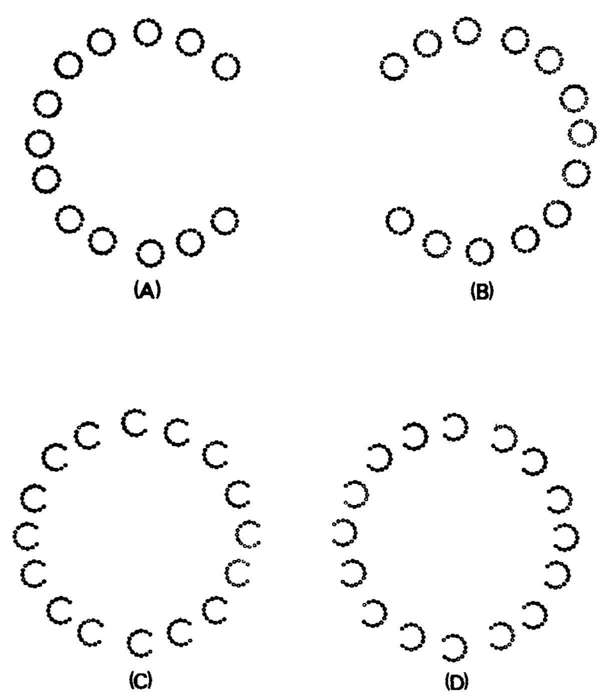


*Figure 2.* Examples of Navon and Norman's (1983) compound figures. (From "Does Global Precedence Really Depend on Visual Angle?" by D. Navon and J. Norman, 1983, *Journal of Experimental Psychology: Human Perception and Performance, 9,* p. 958. Copyright 1983 by the American Psychological Association. Reprinted by permission.)

ings. However, Kimchi (1988) used a simultaneous comparison task, and found global advantage with fixed peripheral presentations of hierarchical geometrical patterns in some conditions but not in others, depending on the stimuli and on the presence or absence of conflicting output between the global and local levels. Lamb and Robertson (1988, Experiments 1 & 3) compared performance for uncertain central and peripheral presentations and found faster reaction times and less interference at the local but not at the global level for central presentations, indicating that central, local processing benefits from an increase in acuity, independent of spatial uncertainty. These findings render spatial uncertainty as the possible source of the difference between central and peripheral presentations less plausible, although they do not imply that spatial uncertainty cannot affect global advantage (see below). Second, the absence of global advantage with central presentations may be due to a confounding between globality and eccentricity (see Navon & Norman, 1983). Indeed, when eccentricity was held constant, Navon and Norman found global advantage with stimuli that were presented with central fixation.

*Spatial uncertainty.* Lamb and Robertson (1988) found that central presentations resulted in faster reaction times at the local level when they were fixed (i.e., under spatial certainty, Experiment 2) than when they were intermixed with peripheral presentations (i.e., under spatial uncertainty, Experiment 1). Although this finding is a bit problematic because it involves a comparison between experiments, it suggests that spatial uncertainty may affect the presence or absence of global advantage. However, Kimchi and Merhav (1991, Experiment 1), using hierarchical geometrical patterns, found mutual interference between the global and the local levels (i.e., no global advantage) with unpredictable central presentations, and Kinchla and Wolfe (1979) and Miller (1981a, Experiment 2) found global advantage with fixed central presentations. Navon and Norman (1983) also found global advantage with complete spatial certainty when eccentricity was controlled.

*Sparsity and number of local elements.* Martin (1979), using a Stroop-like task with hierarchical letters, examined the effect of sparsity (i.e., the spacing between the local elements) on global/local advantage by varying the number of the local letters while keeping the overall visual angle constant. She found global advantage with the less sparse stimuli and local advantage with the sparse one. Navon (1983), using a same–different task with geometrical patterns, found that the speed of detecting global differences between rectangular patterns was independent of the number of elements. With triangular patterns, however, presented under the same conditions, an effect of the number of elements similar to the one found by Martin (1979) was observed. The effect of number of elements can be explained partly by the confounding between number of elements and "goodness" of the global figure. For example, in Martin's experiment, the global letters composed of sparse local letters were not as good letter exemplars as were the local ones, which could make it more difficult for the subjects to extract the identity of the global letter than the identity of the local letter (see also Navon, 1983). However, Kimchi (1988), using a simultaneous comparison task with geometrical patterns and manipulating the comparison output (i.e., same, different) on the two levels, found global advantage with the few-element patterns but not with the many-element patterns when compatible output at the two levels was present. When incompatible output was present, global advantage was observed with the many-element patterns, but the few-element patterns yielded mutual interference effects. It seems, then, that no consistent effect can be attributed to number of elements or their sparsity, independent of other factors such as the contours of the global figure and task demands.

*Goodness of form.* Hoffman (1980) used compound letters in a memory-scanning task and found that distorting the local letters produced faster reaction times to the global letters and distorting the global letters produced faster reaction times to the local letters. Sebrechts and Fragala (1985) used a sequential same–different task and varied the goodness of the patterns. Good patterns were processed faster when they constituted the relevant level. When a level was irrelevant, good patterns slowed responding through stronger response competition. These findings suggest that global advantage may depend on the quality of the information present at the global and the local level.

*Exposure duration.* Paquet and Merikle (1984) found that the interference pattern between the global and the local letters is affected by exposure duration. They presented compound letters for 10, 40, or 100 ms and found unidirectional global-to-local interference only at the shortest exposure duration. At the longer exposure durations, mutual interference effects were observed even though the global aspect was identified faster than the local one. However, in other studies, global advantage measured by relative speed of processing and by asymmetric interference was observed at longer exposure durations as well (e.g., Hughes, Layton, Baird, & Lester, 1984; Kimchi, 1988; Miller, 1981a; Paquet & Merikle, 1988; Pomerantz, 1983; Wandmacher & Arend, 1985).

*Attention allocation.* Several experiments have shown that attentional manipulations can affect the speed at which global and local information is processed. Comparison of dividing attention between the global and the local levels (i.e., conditions in which both levels were relevant) to focusing attention on a single level showed that when attention was divided between the two levels, global targets had no advantage and, furthermore, directing attention to a single level facilitated performance equally for global and local targets (Hoffman, 1980, Kimchi, Gopher, Rubin, & Raij, in press). Hoffman (1980) interpreted these results as indicating that the speed of processing at a given level may depend on the processing effort allocated to that level. Contrary to Hoffman's results, Navon and Norman (1983) failed to find effects of allocation of attention: The global advantage observed in the divided-attention condition was not more pronounced than in the selective-attention condition. However, several other studies also found effects of attention allocation on global advantage. Ward (1982) examined how prior allocation of attention to the global or the local level can affect the speed with which a current stimulus is processed. His results indicated that identifications were faster for a given level, global or local, if that same level had just been processed for the preceding stimulus, which Ward termed the *level-readiness effect.* Kinchla, Solis-Macias, and Hoffman (1983) demonstrated further that directing attention to one level rather than the other results in utilizing information from that level more rapidly at the cost of slower use of information from other levels. Their results suggest that observers can select one of two alternative attentional strategies, in which each strategy is optimal for using information from one level but less than optimal for the other. Paquet and Merikle (1988) showed that the direction of attention to the global or the local level of an attended object determined which level (global or local) of a nonattended object was harder to ignore. All these findings seem to suggest that attention plays a role in the effects of global advantage observed.

Although it is somewhat difficult to generalize across all the studies reviewed above because of possible confounds and differences in exposure durations, task variables, and measures, there seems to be a consensus that all else being equal, global advantage, reflected in asymmetric interference effect and/or relative speed of processing, is observed, to the limits of visibility and visual acuity. There is little consensus, however, about the interpretation of the global-advantage effect, particularly regarding the effect's locus or the mechanisms underlying the effect. Before discussing this topic, I want to comment on the argument of relative discriminability, which has been raised in the context of the global-advantage effect.

### *Relative Discriminability*

It has been argued that global advantage may reflect an advantage that would be observed with any two stimuli that differed in discriminability, rather than a mandatory perceptual rule (e.g., Pomerantz, 1983). This argument is based on several findings that seem to indicate that the presence or absence of global advantage may depend on factors affecting the perceptual quality of the information at the global and the local levels (e.g., Grice et al., 1983; Hoffman, 1980; Kinchla & Wolfe, 1979; Paquet & Merikle, 1984; Pomerantz, 1983; Sebrechts & Fragala, 1985). The ability to successfully ignore a stimulus may depend on its discriminability or perceptibility relative to that of the attended stimulus. This point has been made very convincingly by Garner (1974) with regard to his speeded classification paradigm for revealing dimensional interactions. Obviously there are differences in discriminability that need to be controlled for if the processing dominance of one stimulus over the other is to be examined, using selective-attention measures. However, in some cases, it is precisely the difference in discriminability that may be accounted for by the mechanism of interest. For example, if global advantage could be accounted for solely by a greater perceptibility of the global level because of such peripheral factors as visual acuity, it would not constitute support for the existence of the hypothesized mechanism of global precedence. But if all factors not inherent in level of globality that can possibly affect the relative discriminability of the global and the local levels are controlled for, then a greater discriminability of the global level may reflect a predisposition of the perceptual system. The findings reviewed above show that several factors that affect the relative discriminability (or perceptibility) of the global and the local levels have an effect on global advantage (e.g., retinal location). But they also demonstrate that none of these factors seem to constitute necessary and sufficient conditions for obtaining global advantage. Furthermore, there are several findings of global advantage under conditions in which baseline reaction time to global and local levels was equal, presumably reflecting equal discriminability (Ghim & Eimas, 1988; Hughes et al., 1984; Ward, 1982, Experiment 2). Therefore, evoking discriminability per se as an account of global advantage is hardly tenable (see also Navon, 1981b; Robertson & Lamb, 1991). The question still remains whether global advantage is mediated by sensory mechanisms, attentional mechanisms, or both.

### *Source and Locus of the Global-Advantage Effect*

In one of the better controlled experiments within the global/local paradigm, Navon and Norman (1983) demonstrated that relative size is a major determinant of the global-advantage effect. Holding eccentricity constant, they compared test conditions that allowed selective attention to one level of a compound stimulus with no possible interference from the other level (as in identifying the direction of the opening of the C in the stimuli of Figure 2) with a control condition in which a single character of the same size as the local element was presented. Their results showed faster response times to the global (test) condition than to the control condition but no significant difference between response time to the local (test) condition and the control, indicating that larger properties were apprehended faster. On the basis of this finding, they further suggested that global advantage is mediated by sensory mechanisms. This finding is in accordance with that of Shulman, Sullivan, Gish, and Sakoda (1986), who showed a link between the global and the local levels and relative spatial frequencies. Using an adaptation procedure, Shulman and his colleagues found that the adapting frequency that most affected the global task was lower than that affecting the local task. They also found that reaction times to the global level were faster than to the local level at all levels of detectability. These results suggest a role of low-frequency channels in the processing of the global level.

The finding that global advantage is related to stimulus factors such as relative size or relative spatial frequencies does not rule out the possibility that global advantage has an attentional source as well (see also Navon & Norman, 1983). Shulman and Wilson (1987a) found that directing attention to the local or the global level affected the detectability of different spatial frequencies: Low frequencies were more easily detected when attention was directed to the global level, and high frequencies were more easily detected when attention was directed locally. The studies reviewed earlier showing the effects of attentional manipulations on global advantage (Hoffman, 1980; Kinchla et al., 1983; Lamb & Robertson, 1990; Paquet & Merikle, 1988; Ward, 1982) also suggest that attentional mechanisms may underly the effect of global advantage. The nature of such mechanisms are yet to be determined. There might be some bias in the resource allocation policy or some mechanism that accentuates the sensory advantage under concurrent presentation, such as an asymmetric inhibition interaction between high-frequency and low-frequency channels (Hughes et al., 1984; Navon & Norman, 1983).

Contrary to Navon's (1977, 1981b) interpretation of global advantage as reflecting the priority of global properties at early perceptual processing, several investigators suggested that global advantage arises in some postperceptual process. Miller (1981a) used a target search task that required the subjects to attend to both global and local information and found that local information had a large influence on reaction time even when information at the global level was sufficient to determine the response. Supported by analysis of cumulative density functions of response latencies, Miller (1981a) proposed a model in which detection of global and local information takes place in parallel and become available to decision processes with the same time course. Consequently, he suggested that decision and response selection processes, rather than those of property extraction and detection, operate in a global-to-local fashion. Boer and Keuss (1982) examined the initial regions of speed–accuracy trade-off functions under global and local classification judgments, both with geometrical figures (Experiment 1) and with hierarchical letters (Experiment 2). Their analysis indicated initial similar time courses for global and local detection. They concluded that the absence of an initial global advantage argues for a postperceptual locus of the effect, "somewhere between perception and response selection" (Boer & Keuss, 1982, p. 365). Ward (1982) suggested, on the basis of the attentional effects he found, that the locus of global advantage may be at the stage of features integration, a stage which has been assumed to require focal attention (e.g., Treisman & Gelade, 1980).

However, in addition to the studies of Navon and Norman (1983) and Shulman and Wilson (1987a) mentioned earlier, which suggest that global advantage is a perceptual effect, several other studies also provide data in support of the hypothesis that global advantage has its origin in early perceptual processing. Hughes et al. (1984) found that even when the distracting influence of irrelevant variation on the global level was minimized, local reaction times were still slower than global reaction times, a finding that is difficult to reconcile with Miller's (1981a) assertion that global and local information is processed at an equal rate. Hughes et al. also found that under conditions of equal visibility of the global and the local levels, the magnitude of global advantage depended on stimulus luminance. They interpreted their findings as indicating that the advantage of the global level is at least partially attributable to early perceptual processing. Paquet and Merikle (1988) attempted to examine whether global advantage originates during preattentive processing by evaluating the effects of global and local aspects of nonattended figures on the processing of attended figures. They found that the global aspect of a nonattended figure was categorized regardless of whether attention was directed toward the global or the local aspect of the attended figure, although it was not invariably identified. In agreement with other results, global advantage was observed with attended figures. On the basis of these findings, Paquet and Merikle (1988) suggested that a mandatory global processing, at least to the level of stimulus categorization, takes place during preattentive perceptual processing and that it might be the reason for the dominance of the global level of attended objects.

It is not easy to localize the source of global advantage. The difficulty is by no means specific to the effect at hand. Rather, it exemplifies the difficulty inherent in attributing effects of experimental variables to internal processes (e.g., Miller, 1981a, 1981b; Navon, 1981a; Uttal, 1988). At least two factors contribute to this difficulty. First, the manifestation of an effect in a postperceptual process such as response competition does not, by itself, rule out the possibility that the effect has its origin in earlier perceptual processing (see also Hughes et al., 1984; Navon, 1981a). Second, different tasks may tap different stages of processing or evoke different optional strategies available to the processing system (e.g., Kimchi, 1988; Kimchi & Goldsmith, in press; Pomerantz, 1983; Pomerantz, Pristach, & Carson, 1989; Treisman, 1986). For example, Kimchi and Palmer (1985) found, using a speeded classification task, that form and texture of many-element patterns were perceptually separable: Subjects were able to selectively attend to either dimension without interference from irrelevant variation on the other dimension. However, in a simultaneous-comparison task, asymmetric interference was observed when a potential conflicting output between these dimensions was present (Kimchi, 1988). Other similar findings have been reported, demonstrating that with separable dimensions, selective attention can be possible in one task but not in another, depending on the likelihood of dimensional output conflict (e.g., Santee & Egeth, 1980). These findings suggest that dimensional analysis is a necessary but not sufficient condition for successful selective attention to a stimulus dimension. In a similar vein, local properties may be extracted before the stage of complete identification of the global configuration, depending on task demands. However, it does not rule out the possibility that in early stages of perceptual processing, global properties are available before the local ones.

In addition, some of the findings reported are based on measuring Stroop-type interference, and others are based on measuring Garner-type interference. Pomerantz et al. (1989) provided evidence suggesting that Stroop and Garner measures cannot be used interchangeably to assess attentional selectivity. The situation becomes even more complicated in light of several findings indicating that speed of processing and interference, the two experimental effects on which the global-precedence hypothesis was based, do not always covary (e.g., Lamb & Robertson, 1988, 1989; Navon & Norman, 1983) and they may reflect different modes of processing (Navon & Norman, 1983) or even separate mechanisms (Robertson & Lamb, 1991).

A detailed understanding of the mechanisms underlying the global-advantage effect should await a thorough analysis of the tasks involved in information processing terms (see also Miller 1981a, 1981b; Navon, 1981a, Ward, 1982) and, as hopefully will become clear from the following discussion, an analysis of the perceptual structure of the stimuli studied (see also Kimchi & Goldsmith, in press).

Note that to the extent that relative size or relative spatial frequencies play a role in global/local processing, it is not at all surprising that factors presumably affecting resolution, such as retinal location, eccentricity, spatial uncertainty, and exposure duration, were found to affect global advantage. It has been found that sensitivity to high and low spatial frequencies is greatest at the fovea and falls off with eccentricity. However, the falloff in sensitivity with eccentricity is not as great for low as for high spatial frequencies (e.g., Shulman & Wilson, 1987b). Consequently, retinal location and eccentricity can modulate the size of the global-advantage effect (e.g., Grice et al., 1983; Kinchla & Wolfe, 1979). It has been also found that exposure duration has a differential effect on integration of low and high spatial frequencies, so that a decrease in exposure duration is more detrimental for the perception of high than of low frequencies (e.g., Nachmias, 1967). It follows that exposure duration can also affect the obtained global advantage (e.g., Paquet & Merikle, 1984). Models of visual attention (e.g., Eriksen & Yeh, 1985; LaBerge, 1983) suggest a trade-off between the size of the visual field over which attention is distributed and its resolution. According to the "zoom lens" analogy offered by Eriksen and Yeh, when the power of the lens increases, the size of the effective visual field decreases and the capacity for fine discrimination increases (e.g., Eriksen & St. James, 1986). Consequently, spatial uncertainty, presumably a condition of distributed attention, can also affect the size of the global-advantage effect.

Up to this point, I have reviewed the research within the global/local paradigm from a processing point of view. I turn now to examine the perceptual structure of the typical stimuli used, namely that of hierarchical patterns.

## Global/Local Structure

The motivation for examining the perceptual structure of hierarchical patterns is as follows. Within the global/local paradigm, the precedence of global properties is inferred from the perceptual advantage of one level of stimulus structure (the global level) over the other level (the local level). Hence, a basic assumption underlying the research within the global/local paradigm seems to be that there are two distinct perceptual levels corresponding directly to the global configuration and the local elements of hierarchical patterns and that the critical question is which level gets processed first? This supposed correspondence between levels of pattern structure and perceptual levels may hold in some cases and not in others, and thus a clear notion of how hierarchical patterns are structured perceptually is an important prerequisite for asking meaningful questions about how such structure may be processed.

### *Perceptual Structure of Hierarchical Patterns*

Hierarchical patterns are characterized as having two distinct levels of pattern structure: global configuration and local elements. (I use the term *pattern* to refer to the entire stimulus, namely, to both levels at once.) In the perceptual domain, however, three phenomenal aspects can be identified: overall form, figural parts, and texture. Whenever small figures are positioned near each other in such a way that their positions form the pattern of a larger figure, the two levels of pattern structure (i.e., the global configuration and the local elements) are present regardless of the number and/or the relative size of the elements. However, Kimchi (1982/1983; Kimchi & Palmer, 1982) has claimed that the mapping from the two levels of pattern structure in the stimulus domain into meaningful levels in the perceptual domain depends critically on the number and the relative size of the elements.

Phenomenologically, patterns composed of many relatively small elements (many-element patterns) are perceived as overall form associated with texture. Patterns composed of few relatively large elements (few-element patterns) are perceived as overall form and figural parts. The local elements of many-element patterns lose their function as individual parts of the form and are relegated to the role of "material" (Goldmeier, 1936/1972) or "texture" (Kimchi, 1982/1983; Kimchi & Palmer, 1982) and do not interact with the form of the pattern. That is, the global form and the local elements of many-element patterns are phenomenally independent: Replacing the elements of the patterns by other elements does not affect the perception of its overall form. On the other hand, the local elements of few-element patterns are perceived as figural parts of the overall form. Pomerantz (1981, 1983) independently proposed a similar phenomenal distinction between two types of patterns. In what Pomerantz termed "Type P" patterns, only the position of the local elements matters for the overall form. In "Type N" patterns, both the position and the nature of the local elements matter.

Kimchi (1982/1983, 1988, 1990; Kimchi & Palmer, 1982, 1985) used several converging operations to support this distinction operationally. In a forced-choice similarity-judgment task (originally used by Goldmeier 1936/1972), subjects were presented with stimulus triads composed of a standard pattern and two comparison patterns. One comparison pattern was a proportional enlargement of the standard pattern (i.e., an enlargement in which the size of both the global configuration and the local elements is increased by uniform dilation). The other comparison pattern was a particular sort of unproportional enlargement in which the global configuration is enlarged but not the size of and the distance between the elements (see Figure 3). Few-element patterns were judged to be more similar to their proportional enlargements, which preserved both the global and the local structures as well as the relationships between them. Many-element patterns, on the other hand, were judged to be more similar to their unproportional enlargements, which preserved the global form as well as the texture of the pattern (Goldmeier, 1936/1972; Kimchi, 1990, Experiment 1; Kimchi & Palmer, 1982, Experiment 1).

The relative salience of the local element in few- and many-element patterns was examined using a similarity-judgment task involving stimulus triads in which the global configuration was pitted against the local elements (see Figure 4). Few-element patterns were judged to be more similar to a same-element pattern (i.e., a pattern in which the same elements are arranged to form a different configuration) than to a same-configuration pattern (i.e., a pattern in which different elements are arranged to form the same configuration), but many-element patterns were judged to be more similar to a same-configuration pattern than to a same-element pattern (Kimchi, 1990, Experiment 2; Kimchi & Palmer, 1982, Experiment 2). Subjects' preferences for verbal descriptions of the patterns were also consistent with the similarity judgments. When presented with descriptions in which the global configuration was the grammatical subject and the local elements were the grammatical object (e.g., "a triangle made of triangles") and descriptions in which the global configuration and the local elements had a reversed role (e.g., "triangles arranged to form a triangle"), subjects preferred the former kind of descriptions for many-element patterns and the latter kind of description for few-element patterns (Kimchi & Palmer, 1982, Experiment 4).

In a parametric study using the two similarity-judgment

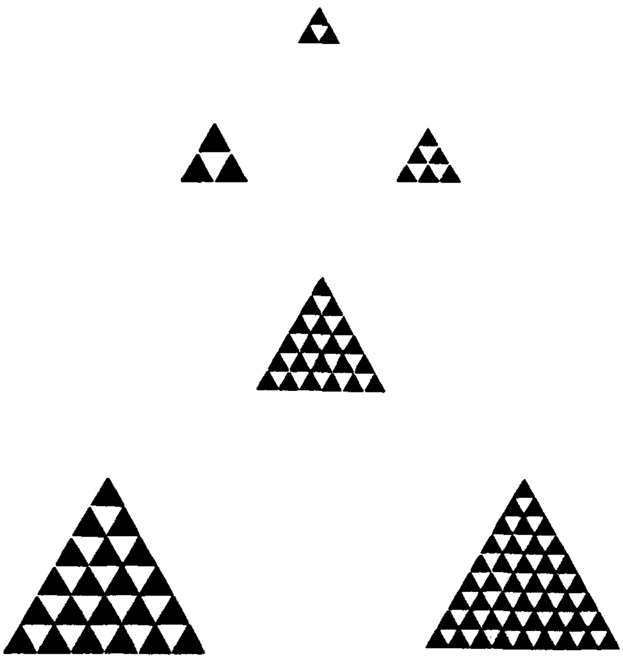

*Figure 3.* Examples of the stimulus triads used in Kimchi and Palmer's (1982) study (Experiment 1) with adults and in Kimchi's (1990) study (Experiment 1) with children. (From "Form and Texture in Hierarchically Constructed Patterns" by R. Kimchi and S. E. Palmer, 1982, *Journal of Experimental Psychology: Human Perception and Performance, 8,* p. 524. Copyright 1982 by the American Psychological Association. Adapted by permission.)

tasks described above, the number of elements and their relative size were varied systematically. The results showed that the critical number of elements for which the switch in the similarity judgments occurred was 7 ± 2, both for adults (Kimchi, 1982/1983; Kimchi & Palmer, 1982) and for children as young as 3 years of age (Kimchi, 1990).

Converging evidence was then obtained for the perceptual separation/nonseparation of global and local levels in hierarchical patterns as a function of the number of elements in the pattern. In a speeded classification task involving a set of four patterns created by orthogonally combining two types of global configuration and two types of local elements (see Figure 5), subjects were required to classify the patterns according to either global form or texture. Few-element patterns showed a pattern of results that is typical of integral dimensions (cf. Garner, 1974): Facilitation was obtained when the global configuration and the local elements were combined redundantly, and interference was obtained when they were combined orthogonally. Many-element patterns, on the other hand, showed a pattern of results typical of separable dimensions: No facilitation was obtained when the global configuration and the local elements were combined redundantly, and no interference was obtained when they were combined orthogonally (Kimchi & Palmer, 1985, Experiments 1 & 3).

Few-element and many-element patterns also produced reliably different patterns of results in a simultaneous-comparison task in which subjects were required to determine whether two simultaneously presented patterns were the same or different at the global or at the local level (Kimchi, 1988) and in an identification task using a Stroop-like interference paradigm (Kimchi & Merhav, 1991, Experiment 2), both using the same stimuli as in the speeded classification task.

The requirement to classify the same patterns according to global and local forms (rather than in terms of global form and texture) did not affect the pattern of results obtained with the few-element patterns (Kimchi, 1988; Kimchi & Merhav, 1991; Kimchi & Palmer, 1985, Experiments 2 & 4). This could be expected from the relation between number of pattern elements and the "appearance" of texture. Inasmuch as a critical number of elements (around 7 ± 2) are required for texture perception, there is simply no perceived texture in few-element patterns. For many-element patterns, on the other hand, there is a difference between texture and local form. Whereas global form and texture of many-element patterns were found to be perceptually separable, the requirement to classify such patterns in terms of global and local forms did result in interference between the levels (Kimchi, 1988; Kimchi & Merhav, 1991, Experiment 1; Kimchi & Palmer, 1985, Experiments 2 and 4).

Further evidence for the perceptual separation/nonsepara-

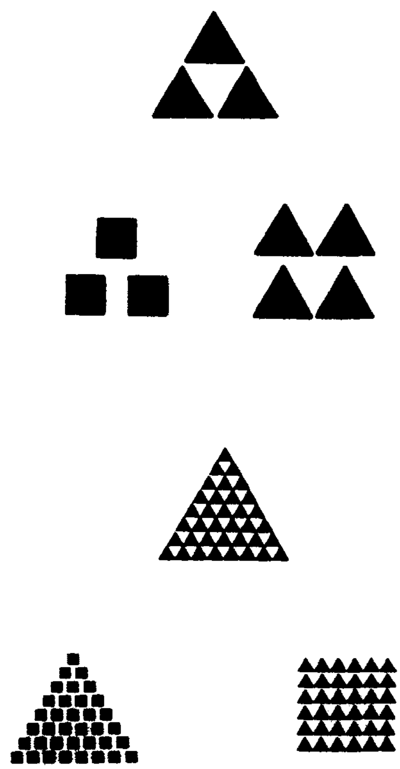

*Figure 4.* Examples of the stimulus triads used in Kimchi and Palmer's (1982) study (Experiment 2) with adults and Kimchi's (1990) study (Experiment 2) with children. (From "Form and Texture in Hierarchically Constructed Patterns" by R. Kimchi and S. E. Palmer, 1982, *Journal of Experimental Psychology: Human Perception and Performance, 8,* p. 526. Copyright 1982 by the American Psychological Association. Adapted by permission.)

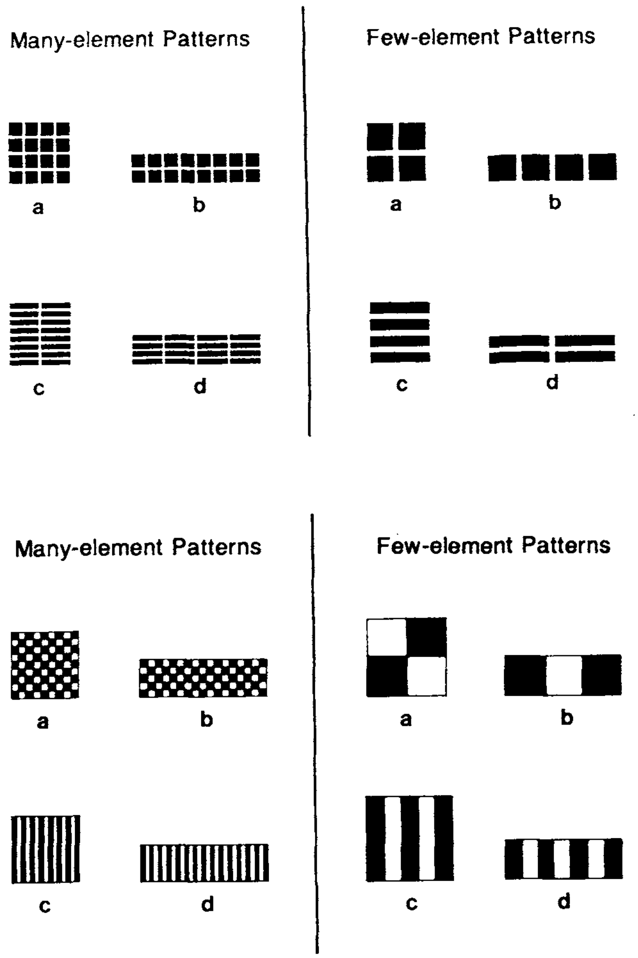


*Figure 5.* The four sets of stimuli used in Kimchi and Palmer's (1985) study and in Kimchi and Merhav's (1991) study. (The stimulus pairs used in Kimchi's, 1988, study were created from the two upper sets. From "Separability and Integrality of Global and Local Levels of Hierarchical Patterns" by R. Kimchi and S. E. Palmer, 1985, *Journal of Experimental Psychology: Human Perception and Performance, 11,* pp. 676 & 682. Copyright 1985 by the American Psychological Association. Adapted by permission.)

tion between the global and local levels of many- and few-element patterns, respectively, has been obtained with similarity judgments and speeded classification using different stimuli (Klein & Barresi, 1985).

In summary, this body of evidence suggests that there is a good reason to distinguish the perceptual structure of patterns composed of many, relatively small, elements from that of patterns composed of few, relatively large, elements. The two types of stimuli show clearly distinguishable performance characteristics across different tasks and across subjects (adults and children). In particular, the local elements of few-element patterns are perceived as figural parts of the overall form, and the global and local levels are perceptually integral. On the other hand, the local elements of many-element patterns are perceived as textural molecules, and the overall form and the texture of such patterns are perceptually separable.

This line of research demonstrates the importance of defining properties *psychophysically* rather than just physically (Garner, 1974). The findings presented above clearly show that the same stimulus properties as defined by the experimenter (i.e., global configuration and local elements) are not treated equivalently by subjects for few- and many-element patterns. The local elements are physically present in hierarchical patterns, and they have the same logical status, regardless of number of elements. However, the perceptual property is either texture or figural part, depending on the number and relative size of the local elements.

A discrepancy between the effective perceptual units as defined by the experimenter and those having psychological reality in the perceptual system may cause the experimenter to commit an inferential error regarding the proper characterization of perceptual processing. Navon (1981b) pointed out, and rightly so, that "strictly speaking, global precedence cannot be tested unless it is known what the perceptual units are" (p. 27), and because there is not yet a clear idea as to what the perceptual units are, Navon suggested that "we have to rely on our common sense reinforced by our knowledge of Gestalt laws of organization" (p. 27). This is precisely why the stimulus structure used to test a processing hypothesis has to be carefully analyzed and supported in psychophysical terms.

The perceptual mechanisms underlying the perceptual structure of hierarchical patterns are yet to be determined. Obviously, the logical structure of such patterns does not predict the processing consequences observed with these patterns (see also Garner, 1983). Hierarchical patterns may be seen as providing a clear case of asymmetry in the logical structure of the stimuli: Local elements can exist without a global configuration, but a global configuration cannot exist without local elements (e.g., Pomerantz & Sager, 1975), and this asymmetry holds for both few- and many-element patterns. The logical structure cannot account for the different perceptual relation between the configural and elemental level in few- and many-element patterns without redefining the logically given relations. From strictly a processing point of view, it might be argued that the very fact that local elements of many-element patterns are perceived as textural molecules is precisely due to global precedence itself (e.g., Navon, 1981b). This argument, however, has difficulty explaining why, in contrast to many-element patterns, the local elements of few-element patterns are perceived as figural parts.

The converging evidence for the difference in the perceptual stimulus structure of few- and many-element patterns seems to have several important implications for the global/local paradigm.

## *Implications for the Global/Local Paradigm*

As noted earlier, the choice of hierarchical patterns for testing the global-precedence hypothesis was guided by the assumption that the global configuration and the local elements constitute two distinct, independent structural levels, which map directly into two perceptual levels that differ only in their level of globality. However, the finding that the perceptual separation of configural and elemental levels of hierarchical patterns depends on the number and relative size of the elements and that local elements are sometimes perceived as distinctive parts of the overall form, and at other times as textural molecules, challenges the validity of this assumption and has implications for interpretation of the experimental findings obtained in the global/local paradigm.

The asymmetric interference effects used to infer global precedence may depend on the relative perceptual separation between the global and the local levels. To the extent that the local elements and the global configuration are perceptually integral, mutual interference between the two levels is much more likely than when the two levels are perceptually separable. As we have seen, the relative perceptual separation depends, at least in part, on the number and relative size of the local elements. It follows, then, that positing precedence of the global level of structure (as operationalized in the present paradigm) as a rigid perceptual law is hardly tenable. It can be argued that the typical stimuli used in the global/local paradigm are many-element patterns for which a perceptual separability between the two levels has been demonstrated. But then, the following argument may pose a difficulty for interpretations on the basis of performance with many-element patterns.

If the local elements of many-element patterns serve to define texture, then they may not be represented as individual figural units at all. Therefore, it is not clear whether a faster identification of the global configuration should be accounted for by its level of globality, thus suggesting global precedence, or, rather, by a qualitative difference between figural unit and textural molecule. Further research is needed to understand the perceptual status of an element in a many-element pattern with regard to its figural representation.

There is also a further implication that stems from the characterization of the local level in many-element patterns as texture. It is frequently claimed that texture segregation occurs early in perceptual processing; it organizes the visual field and defines the units for further processing. Experimental evidence suggests that texture segregation depends on local properties of the texture molecules (e.g., Beck, 1982; Julesz, 1981; Treisman, 1985). This, in turn, would suggest that properties of the local elements in many-element hierarchical patterns are extracted before those of the global configuration, even though they do not seem to affect the speed of response to identify the global configuration.

The global-precedence hypothesis was formulated in a framework that assumes that a visual object can be described as composed of levels of structure. A forest with its trees, a face with its nose, mouth, eyes, and so on, and the arch made of stones described by Marco Polo can be submitted to such a description, but the units at the lower level of structure in each of these objects have different function in relation to the whole. For example, the eyes, nose, and mouth of a face are its parts, but the stones in the arch are mere constituents, material elements. Hierarchical descriptions are most often viewed as the product of a decomposition of a visual object into parts and parts of parts (e.g., Kinchla et al., 1983; Palmer, 1977; Treisman, 1986). Hierarchical patterns such as the compound letters provide an elegant control for many intervening variables that make it difficult to examine order of processing structural levels of real-world objects. However, although the hierarchical structure is indeed transparent in the typical stimuli used, the functional role of the units at the lower level of structure is not taken into consideration. This also seems to be the basis for Pomerantz's (1981, 1983) criticism of the typical hierarchical patterns used to test the global-precedence hypothesis. One may require the lower level units to function as parts of the overall form. It was from this point of view that I suggested elsewhere (e.g., Kimchi & Goldsmith, in press; Kimchi & Palmer, 1985) that few-element patterns may be better suited to test the global-precedence hypothesis than many-element patterns. This is because the local elements of few-element patterns seem to have psychological reality as component parts of the overall form but the local elements of many-element patterns do not. In any case, the evidence presented here strongly suggests that understanding the perceptual structure of a visual object in terms of the functional relations between the whole and its elements may be an important prerequisite for asking meaningful processing questions.

## Levels of Structure and Wholistic Properties

In view of the evidence presented in this article, the use of hierarchical patterns for testing the global-precedence hypothesis seems to raise two problems, despite its elegance in controlling for many nuisance variables. First, a basic assumption underlying the use of hierarchical patterns is that the two levels of hierarchical patterns, the global configuration and the local elements, map directly into distinct perceptual units that differ only in their level of globality. However, I have presented evidence (Kimchi, 1982/1983; Kimchi, 1988, 1990, Kimchi & Merhav, 1991; Kimchi & Palmer, 1982, 1985) that the local elements map into different perceptual units and that the configural and elemental levels bear different perceptual relations to each other, depending on the number and the relative size of the local elements. Such evidence severely weakens the plausibility of this assumption and has important implications for the interpretation of obtained experimental findings within the global/local paradigm.

Second, relative size alone, rather than level of globality, may provide a reasonable account for obtained global advantage with hierarchical patterns (Navon & Norman, 1983). To the extent that globality is inherently confounded with relative size, the finding that larger properties are available earlier than relatively smaller properties would be informative. But certainly more than this is claimed by the global-precedence hypothesis. The interesting and essential difference between wholistic (global) and component (local) properties is not necessarily their relative size. Consider, for example, a square. To distinguish the wholistic property of closure from the component vertical and horizontal lines on the basis of their relative size would seem to miss the point. Rather, the essential characteristic of wholistic properties is that they do not inhere in the components, but depend instead on the interrelations among them. Therefore, the notion of global precedence as it has been operationalized within the global/local paradigm and its relation to the primacy of wholistic properties need to be reexamined.

### *Global Versus Wholistic Properties*

It was mentioned earlier that within the global/local paradigm, level of globality was defined in terms of levels of stimulus structure. Given this operational definition, the hypothesis actually tested using hierarchical patterns is that processing of properties of higher level units precedes processing of properties of lower level units (Kimchi, 1982/1983; Navon, 1981b; Ward, 1982). This is a legitimate and viable hypothesis, but it is not the same as testing the hypothesis that processing of wholistic properties of a visual object precedes processing of its component properties. For example, one can ask whether apprehension of the roundness of a face (a global property) precedes apprehension of the roundness of the eyes (a local property). But this is not the same as asking whether apprehension of a certain property defined by the interrelations between the face's components (i.e., a wholistic property) is before apprehension of its component parts.[2]

Although the terms *global* and *wholistic* are often used interchangeably, it might be useful to distinguish between them. When levels of globality are equated with levels of stimulus structure, as in the global/local paradigm, properties at the higher level of structure are considered more global than properties at the lower level of structure. Wholistic properties, on the other hand, are, as mentioned before, defined as properties that depend on the interrelations between component parts (see also Garner, 1978; Navon, 1977; Rock, 1986). Such properties are also referred to as *configural* or *emergent* properties (e.g., Garner, 1978; Pomerantz & Pristach, 1989; Rock, 1986; Treisman, 1986), and they are, by definition, *relational* properties. It follows then that not all the properties that would be considered global according to the operational definition in the global/local paradigm are truly wholistic properties, because certain global properties do not depend on the spatial relations among the component parts.

### *Wholistic Versus Component Properties*

Whether wholistic properties dominate component properties at a certain level of processing or whether they are extracted earlier than component properties are empirical questions yet to be answered. To properly test the hypothesis about the perceptual primacy of wholistic properties, it is necessary to find out what are the psychological wholistic and component properties and to pit the two against each other. Granted that wholistic properties and component properties are different aspects of the stimulus but they are not necessarily independent (see also Garner, 1978), it is not easy, though not impossible, to independently manipulate the two. At present, there is some evidence that wholistic, relational properties such as symmetry, parallelism, closure, and intersection do indeed dominate component properties in discrimination and classification tasks (e.g., Lasaga, 1989; Pomerantz & Pristach, 1989; Pomerantz, Sager, & Stoever, 1977). For example it was found that () and )) are more easily discriminated from one another than ( and )—a finding termed *configural superiority effect* by Pomerantz, Sager, and Stoever (1977). It was also found, using the measure of illusory conjunctions devised by Treisman, that relational properties such as closure may be extracted at early stages of perceptual processing (e.g., Kolinsky & Morais, 1986; Treisman & Paterson, 1984).

A somewhat different logic was used in a series of experiments by Lasaga (1989) and Kimchi (1992). They reasoned that if the discriminability of component properties can be obtained independently, if it can be shown that discrimination between stimuli that differ in wholistic properties is always easier than discrimination between stimuli that share wholistic properties, irrespective of the discriminability of their component properties, and if classification according to wholistic properties is always easier than classification according to component properties, then wholistic properties, rather than component properties, dominate processing.

Consider for example the four stimuli presented in Figure 6. Two are composed of vertical and horizontal lines (A & C), and the other two are composed of diagonal lines (B & D). With regard to the wholistic properties defined on these component properties, the pair A and B share closure, and the pair C and D share intersection. The discriminability of the component properties of these stimuli was found by Lasaga and Garner (1983) in their study of the oblique effect. They investigated discrimination and classification performance with a total set of four stimuli: vertical line, horizontal line, left diagonal, and right diagonal. Their findings indicated that discrimination between two diagonal lines was more difficult than discrimination between any other pair of stimuli and that classification of the vertical and horizontal lines versus the two diagonal lines was faster than the two other possible classifications. This pattern of results did not predict the pattern of results obtained with the stimuli in Figure 6. For example, the easiest classification was that of the pair A, B versus the pair C, D, presumably according to the wholistic properties of closure versus intersection, rather than that of the A, C versus B, D, as predicted by the discriminability of their components. In addition, Stimulus B was discriminated from D faster than from A, although the discrimination between B and D, at the components level, involved the most difficult discrimination (i.e., between diagonal lines; Lasaga, 1989; Kimchi, 1992).[3] Further research along this line may contribute to our understanding of the role of wholistic properties in human information processing.

## Concluding Remarks

There has been a lot of confusion concerning the question of whether wholistic properties are perceived before or after com-

[2] Some of these interrelations may not even have labels. The fact that there might be properties that are a function of interrelations between components but cannot be consciously labeled is interesting in its own right. However, it does not imply that the perceptual/cognitive system cannot operate on such properties.

[3] Lasaga (1989) found no global or local advantage with "disconnected" hierarchical patterns (e.g., square made of diamonds). Consequently she made a distinction between connected and disconnected stimuli and suggested a sequential global-to-local processing with connected stimuli and a parallel processing with disconnected stimuli. It is very easy, however, to demonstrate processing dominance of wholistic properties with disconnected stimuli as well—just imagine the stimuli in Figure 6 disconnected (Kimchi, 1992). Therefore, I argue that the difference between the pattern of results obtained with connected and disconnected stimuli is not due to connectedness, but rather to the fact that with her disconnected stimuli Lasaga examined the processing of global versus local properties but, with her connected stimuli, she examined the processing of wholistic versus component properties.

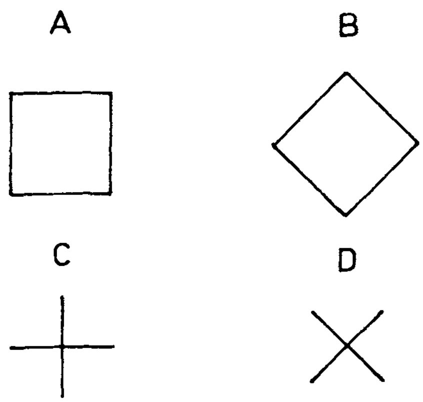


*Figure 6.* Example of a set of stimuli that produce an orthogonal combination of component and wholistic properties. (From "Gestalts and Their Components: Nature of Information Precedence" [p. 190] by M. I. Lasaga, 1989, in B. Shepp and S. Ballesteros, *Object Perception: Structure and Process,* Hillsdale, NJ: Erlbaum. Copyright 1989 by Lawrence Erlbaum Associates, Inc. Adapted by permission.)

ponent properties. No doubt, the global/local paradigm proposed by Navon (1977) is a very elegant and controlled attempt to test this question experimentally. A visual object is viewed as composed of hierarchical levels of structure, and the globality of a property is defined by the place it occupies in the hierarchy. To control for intervening variables while keeping the hierarchical structure transparent, hierarchical patterns are used to test the hypothesis. Review of the empirical findings obtained within the global/local paradigm leads to the conclusion that all else being equal, processing of the global level of hierarchical patterns precedes, or at least dominates, processing of the local level, to the limit of visual acuity. A large body of research has been devoted to examine the locus and the source of the global-advantage effect. There seems to be evidence, though not entirely conclusive, that global advantage occurs at early perceptual processing. Certain findings suggest that the mechanisms underlying the effect may be sensory, but other findings are suggestive of attentional mechanisms.

There is still the need to evaluate the extent to which this line of research sheds light on the issue of wholistic processing. The critical examination of the global/local paradigm and the empirical findings presented in this article strongly suggest that one should be cautious in making inferences about wholistic processing from the processing advantage of the global level of stimulus structure. I will first confine the discussion to wholistic processing as defined within the global/local paradigm. The study of the perceptual structure of hierarchical patterns suggests that levels of stimulus structure do not necessarily map into distinct perceptual units that differ in their level of globality. I reported empirical findings that demonstrate that local elements of hierarchical patterns can map into different perceptual units such as figural parts and textural molecules and that the global and the local levels can bear different perceptual relations to each other, depending on the number and the relative size of the local elements. These findings seem to have important implications for the assumptions underlying the global/local paradigm and for the interpretation of the empirical findings obtained in using it. For example, the advantage of the global level of hierarchical patterns may reflect an advantage of a figural unit versus a textural molecule, rather than an advantage of a global property versus a local one.

In addition, the finding that relative size is a major determinant of global advantage with hierarchical patterns has further, more broad, implications for the notion of globality, as defined in the global/local paradigm, and its relation to the notion of wholistic properties. I have argued above that the essential difference between wholistic and component properties does not seem to be their relative size. Consequently, I proposed a distinction between global properties, defined by their position in the hierarchical structure of the stimulus, and wholistic properties, defined as a function of interrelations between the component parts of the stimulus. Properties at a higher level of structure may dominate properties at a lower level of structure because the perceptual system possibly favors larger properties more than smaller ones. To support the hypothesis of the primacy of wholistic processing, a direct comparison between processing of wholistic properties and component properties on which the wholistic properties are defined is needed. Some empirical findings seem to suggest that wholistic, relational properties, rather than the component properties, dominate perceptual processing.

The question of whether perception is wholistic or analytic will continue to engage the interest of cognitive psychologists. A complete understanding of the perceptual relations between wholes and their parts should await further research and conceptual clarification. These include understanding the perceptual structure of visual objects, analysis of task demands in information-processing terms, and using converging operations that allow inferences regarding temporal precedence. This article suggests that it will be a challenge.

## References


Ballesteros, S. (1989). Some determinants of perceived structure: Effects of stimulus and tasks. In B. Shepp & S. Ballesteros (Eds.), *Object perception: Structure & process* (pp. 235–266). Hillsdale, NJ: Erlbaum.

Beck, J. (1982). Textural segmentation. In J. Beck (Ed.), *Organization and representation in perception* (pp 285–317). Hillsdale, NJ: Erlbaum.

Boer, L. C., & Keuss, P. J. G. (1982). Global precedence as a postperceptual effect: An analysis of speed–accuracy tradeoff functions. *Perception and Psychophysics, 31,* 358–366.

Boff, K. R., Kaufman, L., & Thomas, J. P. (Eds.). (1986). *Handbook of perception and human performance* (Vol. 2). New York: Wiley.

Broadbent, D. E. (1977). The hidden preattentive processes. *American Psychologist, 32,* 109–118.

Bruce, V. (1988). *Recognizing faces.* Hillsdale, NJ: Erlbaum.

Calvino, I. (1974). *Invisible cities* (W. Weaver, Trans.). New York: Harcourt Brace Jovanovich. (Originally work published 1972)

Ehrenfels, C. von. (1890). Über Gestaltqualitäten [On Gestaltqualitäten]. *Vierteljahrschrift fuer Wissenchaftliche Philosophie, 14,* 249–292.

Eriksen, C. W., & St. James, J. D. (1986). Visual attention within and around the field of focal attention: A zoom lens model. *Perception and Psychophysics, 40,* 225–240.

Eriksen, C. W., & Yeh, Y. (1985). Allocation of attention in the visual field. *Journal of Experimental Psychology: Human Perception and Performance, 11,* 583–597.

Foard, C. F., & Kemler Nelson, D. G. (1984). Holistic and analytic modes of processing: The multiple determinants of perceptual analysis. *Journal of Experimental Psychology: General, 113,* 94–111.

Garner, W. R. (1974). *The processing of information and structure.* Hillsdale, NJ: Erlbaum.

Garner, W. R. (1978). Aspects of a stimulus: Features, dimensions, and configurations. In E. Rosch & B. B. Lloyd (Eds.), *Cognition and categorization* (pp. 99–133). Hillsdale, NJ: Erlbaum.

Garner, W. R. (1983). Asymmetric interactions of stimulus dimensions in perceptual information processing. In T. J. Tighe, & B. E. Shepp (Eds.), *Perception, cognition, and development: Interactional analysis* (pp. 1–38). Hillsdale, NJ: Erlbaum.

Ghim, H. R., & Eimas, P. D. (1988). Global and local processing by 3- and 4-month-old infants. *Perception and Psychophysics, 43,* 165–171.

Goldmeier, E. (1972). Similarity in visually perceived forms. *Psychological Issues, 8*(1, Whole No. 29). (Original work published 1936)

Gopher, D., & Kimchi, R. (1989). Engineering psychology. *Annual Review of Psychology, 40,* 431–455.

Grice, G. R., Canham, L., & Boroughs, J. M. (1983). Forest before trees? It depends where you look. *Perception and Psychophysics, 33,* 121–128.

Hoffman, J. E. (1980). Interaction between global and local levels of a form. *Journal of Experimental Psychology: Human Perception and Performance, 6,* 222–234.

Hughes, H. C., Layton, W. L., Baird, J. C., & Lester, L. S. (1984). Global precedence in visual pattern recognition. *Perception and Psychophysics, 35,* 361–371.

Julesz, B. (1981). Textons, the elements of texture perception and their interactions. *Nature, 290,* 91–97.

Kemler, D. G. (1983). Holistic and analytic modes in perceptual and cognitive development. In T. J. Tighe & B. E. Shepp (Eds.), *Perception, cognition, and development: Interactional analysis* (pp. 77–102). Hillsdale, NJ: Erlbaum.

Kemler Nelson, D. G. (1989). The nature and occurrence of holistic processing. In B. Shepp & S. Ballesteros (Eds.), *Object perception: Structure & process* (pp. 357–386). Hillsdale, NJ: Erlbaum.

Kimchi, R. (1983). Perceptual organization of visual patterns (Doctoral dissertation, University of California, Berkeley, 1982) *Dissertation Abstracts International, 44,* 345B.

Kimchi, R. (1988). Selective attention to global and local levels in the comparison of hierarchical patterns. *Perception and Psychophysics, 43,* 189–198.

Kimchi, R. (1990). Children's perceptual organization of hierarchical patterns. *European Journal of Cognitive Psychology, 2,* 133–149.

Kimchi, R. (1992). *Perceptual primacy of wholistic properties.* Manuscript in preparation.

Kimchi, R., & Goldsmith, M. (in press). Structure and process in perceptual organization. In B. Burns (Ed.), *Percepts, concepts, and categories: The representation and processing of information.* Amsterdam: Elsevier.

Kimchi, R., Gopher, D., Rubin, Y., & Raij, D. (in press). Dichoptic and binocular viewing: Effects of attention and task requirements. *Human Factors.*

Kimchi, R., & Merhav, I. (1991). Hemispheric processing of global form, local form, and texture. *Acta Psychologica, 76,* 133–147.

Kimchi, R., & Palmer, S. E. (1982). Form and texture in hierarchically constructed patterns. *Journal of Experimental Psychology: Human Perception and Performance, 8,* 521–535.

Kimchi, R., & Palmer, S. E. (1985). Separability and integrality of global and local levels of hierarchical patterns. *Journal of Experimental Psychology: Human Perception and Performance, 11,* 673–688.

Kinchla, R. A., Solis-Macias, V., & Hoffman, J. (1983). Attending to different levels of structure in a visual image. *Perception and Psychophysics, 33,* 1–10.

Kinchla, R. A., & Wolfe, J. M. (1979). The order of visual processing: "Top down," "bottom up" or "middle-out." *Perception and Psychophysics, 25,* 225–231.

Klein, R. M., & Barresi, J. (1985). Perceptual salience of form versus material as a function of variations in spacing and number of elements. *Perception and Psychophysics, 37,* 440–446.

Koffka, K. (1963). *Principles of Gestalt psychology.* New York: Harcourt, Brace & World. (Original work published 1935)

Kohler, W. (1929). *Gestalt psychology.* New York: Liveright.

Kohler, W. (1971). Human perception. In M. Henle (Ed. and Trans.), *The selected papers of Wolfgang Kohler* (pp. 142–167). New York: Liveright. (Original work published 1930).

Kolinsky, R., & Morais, J. (1986). Evidence for early extraction of emergent properties in visual perception: A replication. *Perceptual and Motor Skills, 63,* 171–174.

Kubovy, M., & Pomerantz, J. R. (Eds.). (1981). *Perceptual organization.* Hillsdale, NJ: Erlbaum.

LaBerge, D. (1983). Spatial extent of attention and words. *Journal of Experimental Psychology: Human Perception and Performance, 9,* 371–379.

Lamb, M. R., & Robertson, L. C. (1988). The processing of hierarchical stimuli: Effects of retinal locus, locational uncertainty, and stimulus identity. *Perception and Psychophysics, 44,* 172–181.

Lamb, M. R., & Robertson, L. C. (1989). Do response time advantage and interference reflect the order of processing of global- and local-level information? *Perception and Psychophysics, 46,* 254–258.

Lamb, M. R., & Robertson, L. C. (1990). The effect of visual angle on global and local reaction times depends on the set of visual angles presented. *Perception and Psychophysics, 47,* 489–496.

Lasaga, M. I. (1989). Gestalts and their components: Nature of information-precedence. In B. Shepp & S. Ballesteros (Eds.), *Object perception: Structure & process* (pp. 165–202). Hillsdale, NJ: Erlbaum.

Lasaga, M. I., & Garner, W. R. (1983). The effect of line orientation on various information-processing tasks. *Journal of Experimental Psychology: Human Perception and Performance, 9,* 215–225.

Lindsey, P. H., & Norman, D. A. (1977). *Human information processing.* San Diego, CA: Academic Press.

Lockhead, G. R. (1972). Processing of dimensional stimuli: A note. *Psychological Review, 79,* 410–419.

Martin, M. (1979). Local and global processing: The role of sparsity. *Memory & Cognition, 7,* 476–484.

McLean, J. D. (1979). Perspectives on the forest and trees: The precedence of parts and whole in visual processing (Doctoral dissertation, University of Oregon, 1978). *Dissertation Abstracts International, 39,* 6162B–6163B.

Miller, J. (1981a). Global precedence in attention and decision. *Journal of Experimental Psychology: Human Perception and Performance, 7,* 1161–1174.

Miller, J. (1981b). Global precedence: Information availability or use? Reply to Navon. *Journal of Experimental Psychology: Human Perception and Performance, 7,* 1183–1185.

Nachmias, J. (1967). Effect of exposure duration on visual contrast sensitivity with square-wave gratings. *Journal of the Optical Society of America, 57,* 421–427.

Navon, D. (1977). Forest before trees: The precedence of global features in visual perception. *Cognitive Psychology, 9,* 353–383.

Navon, D. (1981a). Do attention and decision follow perception? Comment on Miller. *Journal of Experimental Psychology: Human Perception and Performance, 7,* 1175–1182.

Navon, D. (1981b). The forest revisited: More on global precedence. *Psychological Research, 43,* 1–32.

Navon, D. (1983). How many trees does it take to make a forest? *Perception, 12*, 239–254.

Navon, D., & Norman, J. (1983). Does global precedence really depend on visual angle? *Journal of Experimental Psychology: Human Perception and Performance, 9*, 955–965.

Neisser, U. (1967). *Cognitive psychology.* New York: Appleton-Century-Crofts.

Palmer, S. E. (1977). Hierarchical structure in perceptual representation. *Cognitive Psychology, 9*, 441–474.

Paquet, L., & Merikle, P. M. (1984). Global precedence: The effect of exposure duration. *Canadian Journal of Psychology, 38*, 45–53.

Paquet, L., & Merikle, P. M. (1988). Global precedence in attended and nonattended objects. *Journal of Experimental Psychology: Human Perception and Performance, 14*, 89–100.

Pomerantz, J. R. (1981). Perceptual organization in information processing. In M. Kubovy & J. R. Pomerantz (Eds.), *Perceptual organization* (pp. 141–179). Hillsdale, NJ: Erlbaum.

Pomerantz, J. R. (1983). Global and local precedence: Selective attention in form and motion perception. *Journal of Experimental Psychology: General, 112*, 511–535.

Pomerantz, J. R., & Pristach, E. A. (1989). Emergent features, attention, and perceptual glue in visual form perception. *Journal of Experimental Psychology: Human Perception and Performance, 15*, 635–649.

Pomerantz, J. R., Pristach, E. A., & Carson, C. E. (1989). Attention and object perception. In B. Shepp & S. Ballesteros (Eds.), *Object perception: Structure & process* (pp. 53–89). Hillsdale, NJ: Erlbaum.

Pomerantz, J. R., & Sager, L. C. (1975). Asymmetric integrality with dimensions of visual pattern. *Perception and Psychophysics, 18*, 460–466.

Pomerantz, J. R., Sager, L. C., & Stoever, R. J. (1977). Perception of wholes and their component parts: Some configural superiority effects. *Journal of Experimental Psychology: Human Perception and Performance, 3*, 422–435.

Rayner, K. & Pollatsek, A. (1989). *The psychology of reading.* Englewood Cliffs, NJ: Prentice-Hall.

Robertson, L. C. (1986). From Gestalt to Neo-Gestalt. In T. J. Knapp & L. C. Robertson (Eds.), *Approaches to cognition: Contrasts and controversies* (pp. 159–188). Hillsdale, NJ: Erlbaum.

Robertson, L. C., & Lamb, M. R. (1991). Neuropsychological contributions to theories of part/whole organization. *Cognitive Psychology, 23*, 299–330.

Rock, I. (1986). The description and analysis of object and event perception. In K. R. Boff, L. Kaufman, & J. P. Thomas (Eds.), *Handbook of perception and human performance* (Vol. 2, pp. 33: 1–71). New York: Wiley.

Rosch, E. (1978). Principles of categorization. In E. Rosch & B. B. Lloyd (Eds.), *Cognition and categorization*, (pp. 27–48). Hillsdale, NJ: Erlbaum.

Rumelhart, D. E. (1977). *Introduction to human information processing.* New York: Wiley.

Santee, J. L., & Egeth, H. E. (1980). Selective attention in the speeded classification and comparison of multidimensional stimuli. *Perception and Psychophysics, 28*, 191–204.

Sebrechts, M. M., & Fragala, J. J. (1985). Variation on parts and wholes: Information precedence vs. global precedence. *Proceedings of the Seventh Annual Conference of the Cognitive Science Society,* 11–18.

Shepp, B. E. (1989). On perceiving objects: Holistic versus featural properties. In B. Shepp & S. Ballesteros (Eds.), *Object perception: Structure & process* (pp. 203–233). Hillsdale, NJ: Erlbaum.

Shepp, B. E., & Ballesteros, S. (Eds.). (1989). *Object perception: Structure & process.* Hillsdale, NJ: Erlbaum.

Shulman, G. L., Sullivan, M. A., Gish, K., & Sakoda, W. J. (1986). The role of spatial-frequency channels in the perception of local and global structure. *Perception, 15*, 259–273.

Shulman, G. L., & Wilson, J. (1987a). Spatial frequency and selective attention to local and global information. *Perception, 16*, 89–101.

Shulman, G. L., & Wilson, J. (1987b). Spatial frequency and selective attention to spatial location. *Perception, 16*, 103–111.

Smith, J. D. (1989). Analytic and holistic processing in categorization. In B. E. Shepp & S. Ballesteros (Eds.), *Object perception: Structure & process.* (pp. 297–323). Hillsdale, NJ: Erlbaum.

Smith, J. D., & Kemler Nelson, D. G. (1984). Overall similarity in adults' classification: The child in all of us. *Journal of Experimental Psychology: General, 113*, 137–159.

Titchener, E. (1909). *Experimental psychology of the thought process.* New York: Macmillan.

Treisman, A. (1985). Preattentive processing in vision. *Computer Vision, Graphics, and Image Processing, 31*, 156–177.

Treisman, A. (1986). Properties, parts, and objects. In K. R. Boff, L. Kaufman, & J. P. Thomas (Eds.), *Handbook of perception and human performance* (Vol. 2, pp. 35: 1–70). New York: Wiley.

Treisman, A., & Gelade, G. (1980). A feature-integration theory of attention. *Cognitive Psychology, 12*, 97–136.

Treisman, A., & Paterson, R. (1984). Emergent features, attention, and object perception. *Journal of Experimental Psychology: Human Perception and Performance, 10*, 12–31.

Uttal, W. R. (1988). *On seeing forms.* Hillsdale: NJ: Erlbaum.

Wandmacher, J., & Arend, U. (1985). Superiority of global figures in classification and matching. *Psychological Research, 47*, 143–157.

Ward, L. M. (1982). Determinants of attention to local and global features of visual forms. *Journal of Experimental Psychology: Human Perception and Performance, 8*, 562–581.

Ward, L. M. (1983). On processing dominance: Comment on Pomerantz. *Journal of Experimental Psychology: General, 112*, 541–546.

Werner, H. (1948). *Comparative psychology of mental development.* New York: International Universities Press.

Wertheimer, M. (1967). Gestalt theory. In W. D. Ellis (Ed.), *A source book of Gestalt psychology* (pp. 1–11). New York: Humanities Press. (Original work published 1925).

Winston, P. H. (1975). Learning structural descriptions from examples. In P. H. Winston (Ed.), *The psychology of computer vision* (157–209). New York: McGraw-Hill.

Wundt, W. (1874). *Grundzüge der physiologischen psychologie* [Principles of Physiological Psychology]. Leipzig, Germany: Engelmann.

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