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Chapter 7

The perception of hierarchical structure

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Introduction

Visual objects are viewed as a prime example of hierarchical structure; they can be defined as "multilevel hierarchical structure of parts and wholes" (Palmer 1977). For instance, a human body is composed of parts—head, legs, arms, etc., which in turn are composed of parts—eyes, nose, and so forth.

The perceptual relations between wholes and their component parts have been a controversial issue for psychologists and philosophers before them. In psychology it can be traced back to the controversy between Structuralism and Gestalt. The Structuralists, rooted firmly in British Empiricism, claimed that perceptions are constructed from atoms of elementary, unrelated local sensations that are unified by associations due to spatial and temporal contiguity. The Gestalt theorists rejected both atomism and associationism. According to the doctrine of holism in traditional Gestalt psychology, a specific sensory whole is qualitatively different from the complex that one might predict by considering only its individual parts, and the quality of a part depends upon the whole in which this part is embedded (Köhler 1930/1971; Wertheimer 1923/1938; see also Wagemans, this volume).

This chapter focuses on some modern attempts to grapple with the issue of part-whole relationships: global precedence and the primacy of holistic properties. I begin with the presentation of the global precedence hypothesis and the global-local paradigm, followed by a brief review of the empirical findings concerning the boundary conditions of the global advantage effect, its source and its brain localization. The following sections focus on the microgenesis and the ontogenesis of the perception of hierarchical structure. I then discuss some issues concerning the interpretation of the global advantage effect, present a refinement of terminology between global properties and holistic/configural properties, and review empirical evidence for this distinction and for the primacy of holistic properties. I close by briefly considering the implications of the empirical evidence for the understanding of the perception of hierarchical structure and part-whole relationship.

Global precedence

The global precedence hypothesis, proposed by Navon (1977), states that perceptual processing proceeds from the global structure towards analysis of more local details. Viewing a visual object as represented by a hierarchical network with nested relationships (e.g., Palmer 1977), 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, a human face: The spatial relationship between the facial components (e.g., eyes, nose, mouth) is more global than the specific shapes of the components, and in turn, the relationship between the subparts of a component is more global than the specific properties of the subparts. The global precedence hypothesis claims that the processing of an object is global to local; namely, more global properties of a visual object are processed first, followed by analysis of more local properties.

The global precedence hypothesis has been tested by studying the perception of hierarchical patterns in which larger figures are constructed by suitable arrangement of smaller figures (first introduced by Asch 1962, and later by Kinchla 1974, 1977). An example is a set of large letters constructed from the same set of smaller letters having either the same identity as the larger letter or a different identity (see Figure 7.1). These hierarchical patterns satisfy two conditions, which were considered by Navon (1977, 1981, 2003) to be critical for testing the hypothesis: first, the global and local structures can be equated in familiarity, complexity, codability, and identifiability, so they differ only in level of globality, and second, the two structures can be independent so that one structure cannot be predicted from the other.

In one experimental paradigm, which has become very popular, observers are presented with such stimuli and are required to identify the larger (global) or the smaller (local) letter in separate blocks of trials. Findings of global advantage—namely, faster identification of the global letter than the local letter and disruptive influence from irrelevant global conflicting information on local identification (global-to-local interference)—are taken as support for the global precedence hypothesis (e.g., Navon 1977, experiment 3).

Much of the research following Navon's (1977) seminal work has been concentrating on delineating boundary conditions of the global advantage effect, examining its locus (perceptual or post-perceptual), and its localization in the brain (see Kimchi 1992, and Navon 2003, for reviews).

Global advantage: boundary conditions. Several studies have pointed out certain variables that can moderate or even reverse the effect. Global advantage is not likely to occur when the overall visual angle of the hierarchical stimulus exceeds 7°—10° (Kinchla and Wolfe 1979; Lamb and Robertson 1990), but the effect is just modulated when eccentricity of both levels is equated (e.g., Amirkhiabani and Lovegrove 1999; Navon and Norman 1983). Global advantage is also less likely to occur with spatial certainty than spatial uncertainty (e.g., Lamb and Robertson 1988), with

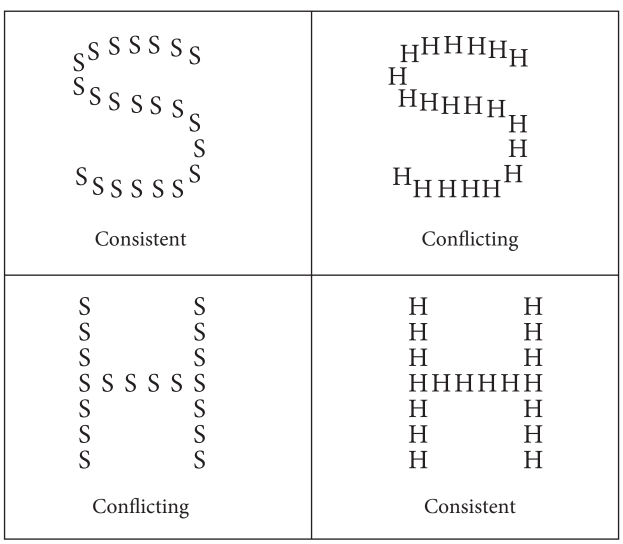

Fig. 7.1 An example of Navon's hierarchical letters: large H's and S's are composed of small H's and S's.
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central than peripheral presentation (e.g., Grice et al. 1983; Pomerantz 1983; but see, e.g., Luna et al. 1990; Navon and Norman 1983), with sparse than dense elements (e.g., Martin 1979), with few relatively large elements than many relatively small elements (Kimchi 1988; Kimchi and Palmer 1982, 1985; Yovel et al. 2001), with long than short exposure duration (e.g., Luna 1993; Paquet and Merikle 1984), and when the goodness of the local forms or their meaningfulness are superior to that of the global form (e.g., LaGasse 1994; Poirel et al. 2006; Sebrechts and Fragala 1985). The global advantage effect can be also modulated by direct and indirect attentional manipulations (e.g., Han and Humphreys 2002; Kinchla et al. 1983; Lamb et al. 2000; Robertson 1996; Ward 1982). For example, Han and Humphreys (2002, experiment 1) showed that when attention was divided between the local and global levels, the presence of a salient local element, which presumably captured attention, speeded responses to local targets while slowing responses to global targets.

The source of global advantage. The source (or the locus) of the global advantage effect is still disputed. Several investigators concluded that the source of global advantage is perceptual (e.g., Andres and Fernandes 2006; Broadbent 1977; Han et al. 1997; Han and Humphreys 1999; Koivisto and Revonsuo 2004; Miller and Navon 2002; Navon 1977, 1991; Paquet 1999; Paquet and Merikle 1988), possibly as a result of early perceptual-organizational processes (Han and Humphreys 2002; Kimchi 1998, 2000, 2003b). The involvement of organizational processes in global advantage is discussed in detail later in the chapter. It has been also suggested that global advantage arises from a sensory mechanism—faster processing of low spatial frequencies than high spatial frequencies (e.g., Badcock et al. 1990; Han et al. 2002; Hughes et al. 1990; Shulman et al. 1986; Shulman and Wilson 1987). Although the differential processing rate of low and high spatial frequencies may play a role in global and local perception, it cannot account for several findings (e.g., Behrmann and Kimchi 2003; Kimchi 2000; Navon 2003). For example, it cannot handle the effects of meaningfulness and goodness of form on global/local advantage (e.g., Poirel et al. 2006; Sebrechts and Fragala 1985). Also, Behrmann and Kimchi (2003) reported that two individuals with acquired integrative visual object agnosia exhibited normal spatial frequency thresholds in both the high- and low-frequency range, yet both were impaired, and differentially so, at deriving the global shape of multi-element hierarchical stimuli. Other investigators suggested that global advantage arises in some post-perceptual process (e.g., Boer and Keuss 1982; Miller 1981a, 1981b; Ward 1982). This view is supported by the findings demonstrating that attention typically modulates the global advantage effect (e.g., Kinchla et al. 1983; Lamb et al. 2000; Robertson 1996), but, as noted by Navon (2003), attention can magnify biases that originate prior to the focusing of attention. Similarly, an effect that arises at the perceptual level can be magnified by post-perceptual processes, such as response-related processes (Miller and Navon 2002).

Global advantage: brain localization. Data from behavioral and functional neuroimaging studies are seen to suggest functional hemispheric asymmetry in global versus local perception, with the right hemisphere biased toward global processing and the left hemisphere biased toward local processing (e.g., Delis et al. 1986; Fink et al. 1997; Kimchi and Merhav 1991; Robertson et al. 1993; Weissman and Woldorff 2005). One view suggests that this asymmetry is related to the relation between spatial frequency processing and global and local perception. Ivry and Robertson (1998; Robertson and Ivry 2000), proponents of this view, proposed that there are two stages of spatial frequency filtering, and the two hemispheres differ in the secondary stage that is sensitive to the relative rather than absolute spatial frequencies. The left hemisphere emphasizes information from the higher spatial frequencies within the initially selected range, and the right hemisphere emphasizes the lower spatial frequencies, with the result that the right hemisphere is preferentially biased to process global information and the left hemisphere local information.

Alternative accounts for the hemispheric asymmetry in global/local processing include the proposal of hemispheric differences in sensitivity to the saliency of the stimulus, with the right hemisphere biased toward more salient objects and the left hemisphere biased toward less salient objects (Mevorach et al. 2006a, 2006b), and the integration hypothesis, which suggests that the hemispheres are equivalent with respect to shape identification but differ in their capacities for integrating shape and level information, with the right hemisphere involved in binding shapes to the global level and the left hemisphere involved in binding shapes to the local level (Hubner and Volberg 2005).

Microgenesis of the perception of hierarchical structure

One approach to understanding the processes involved in perception is to study its microgenesis—the time course of the development of the percept in adult observers. Kimchi (1998) studied the microgenesis of the perception of hierarchical stimuli that vary in number and relative size of their elements, using a variation of the primed matching paradigm (Beller 1971). In this paradigm the observer is presented with a prime followed immediately by a pair of test figures to be matched for identity. Responses to "same" test pairs are faster when the test figures are similar to the prime than when they are dissimilar to it. This paradigm enables us to assess implicitly the observer's perceptual representations, and by varying the duration of the prime and constructing test figures that are similar to different aspects of the prime, we can probe changes in the representation over time (e.g., Kimchi 1998, 2000; Sekuler and Palmer 1992).

The priming stimuli were few- and many-element hierarchical patterns presented for various durations (40—690 ms). There were two types of "same"-response test pairs defined by the similarity relation between the test figures and the prime. In the element-similarity test pair, the figures were similar to the prime in their elements but differed in their global configurations. In the configuration-similarity test pair, the test figures were similar to the prime in their global configurations but differed in their elements. A neutral prime (X) served as a baseline (control) condition for the two types of test pairs. An example of priming stimuli and their respective "same"- and "different"-response test pairs is presented in Figure 7.2a.

The priming measure, calculated for each prime type, indicates how much the prime in question speeded "same" responses to configuration-similarity test pairs relative to element-similarity test pairs. The amount of priming is defined by the difference in "same" reaction time (RT) to an element-similarity test pair versus a configuration-similarity test pair after seeing the prime, minus the baseline RT difference to these test pairs in the control condition. Priming of the configuration should produce priming values of greater than zero, and priming of the elements should produce priming values of less than zero.

The results (Figure 7.2b) show that the global configuration of patterns containing many relatively small elements was primed at brief exposures (see also Razpurker-Apfeld and Kimchi 2007), whereas the local elements of such patterns were primed only at longer exposures. The global advantage typically observed with briefly presented many-element patterns (e.g., Navon 1977; Paquet and Merikle 1984) and before recognition of the local shape (Miller and Navon 2002) is consistent with this finding. The converse pattern of results was obtained with configurations composed of few, relatively large elements: The elements were primed at brief exposures, whereas the global configuration was primed only at longer exposures.

Results concerning the accessibility of the global configuration and local elements of few- and many-element patterns to rapid search (Kimchi 1998; Kimchi et al. 2005) converged with the primed matching results. The global configuration of many-element patterns was accessible to rapid search, whereas search for the local elements of such patterns was effortfull and inefficient. For the

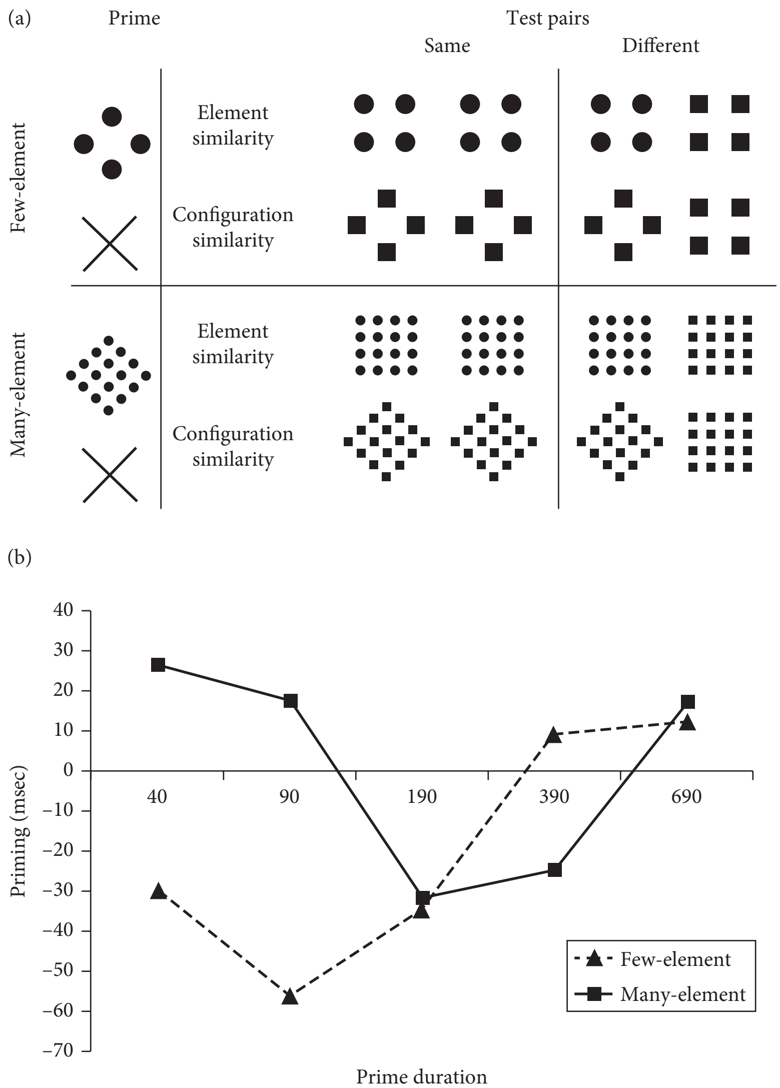

Fig. 7.2 (a) Examples of the priming stimuli and the "same"-response and "different"-response test pairs for the few-element and many-element hierarchical patterns used by Kimchi (1998). (b) Priming effects for the element and many-element patterns as a function of prime duration. Values greater than zero indicate configuration priming; values less than zero indicate element priming (see text for details).
Adapted from Ruth Kimchi, Uniform connectedness and grouping in the perceptual organization of hierarchical patterns, Journal of Experimental Psychology: Human Perception and Performance, 24 (4) pp. 1105–18, DOI: org/10.1037/0096-1523.24.4.1105© 1998, American Psychological Association.

few-element patterns, search for local elements was fast and efficient, whereas the global configuration was searched less efficiently (see also, Enns and Kingstone 1995).

The results of the microgenetic analysis show that the relative dominance of the global configuration and the local elements varies during the evolution of the percept, presumably as a result of grouping and individuation processes that operate in early perceptual processing. Many, relatively small elements are grouped into global configuration rapidly and effortlessly, providing an early

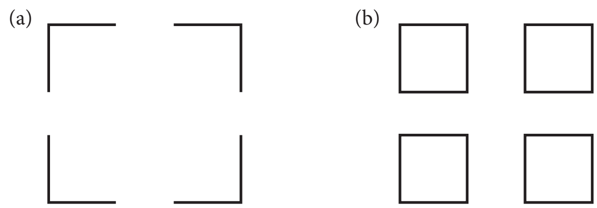

Fig. 7.3 Examples of patterns composed of a few, relatively large elements. (a) Open-ended L elements form a global square. The global square configuration is primed at brief exposure durations, indicating a rapid grouping of the elements. (b) Closed square elements form a global square. The global square configuration is primed only at longer prime durations, indicating time-consuming grouping of the local elements.

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representation of global structure; the individuation of the elements occurs later and appears to be time consuming and attention demanding. Few, relatively large elements, on the other hand, are individuated rapidly and effortlessly and their grouping into a global configuration consumes time and requires attention. Kimchi (1998) suggested that early and rapid grouping of many small elements on the one hand, and early and rapid individuation of a few large elements on the other hand, are desirable characteristics for a system whose one of its goals is object identification and recognition, because many small elements close to one another are likely to be texture elements of a single object, whereas a few large elements are likely to be several discrete objects or several distinctive parts of a complex object.[1]

Notwithstanding the critical role of number and relative size of the elements in the microgenesis of the perception of hierarchical patterns, additional research has suggested that the "nature" of the elements also plays an important role (Han et al. 1999; Kimchi 1994, 2000), further demonstrating the involvement of organizational processes in global advantage. Thus, when the few, relatively large elements are open-ended line segments as opposed to closed shapes (Figure 7.3), their configuration, rather than the elements, is available at brief exposure duration, provided the presence of collinearity and/or closure (Kimchi 2000). Furthermore the advantage of the global level of many-element patterns can be modulated and even vanish, depending on how strongly the local elements group and on the presence of strong cues to segment the local elements, as when closure is present at the local level (Han et al. 1999; Kimchi 1994).

[1] Note that in these hierarchical patterns the number of elements is correlated with their relative size for strictly geometrical reasons: increasing the number of elements necessarily results in decreasing their relative size as long as the overall size of the pattern is kept constant. The effect of relative size can be separated from that of number by constructing patterns in which there are only a few element that are relatively small or large, but if the global size is to be kept constant, other factors, such as relative spacing may be involved. Furthermore, it is impossible to completely isolate the effect of number from the effect of size because the complete orthogonal design combining number and relative size would require a geometrically problematic figure—a pattern composed of many relatively large elements (see Kimchi and Palmer 1982, for discussion).

The development of the perception of hierarchical structure

Studies that examined the perception of hierarchical structure in infancy report that 3- and 4-month old infants are sensitive to both global and local structures of visual stimuli and demonstrate processing advantage for global over local information (Freeseman et al. 1993; Frick et al. 2000; Ghim and Eimas 1988; Quinn et al. 1993; Quinn and Eimas 1986; see also Quinn and Bhatt, this volume).

Studies that examined developmental trends in the processing of hierarchical structure beyond infancy did not yield consistent results. Kimchi (1990) found that children as young as three years of age are as sensitive as adults to the number and relative size of the elements of hierarchical stimuli, demonstrating a local bias for few-element patterns, and a global bias for many-element patterns. Several studies reported that global processing in hierarchical visual stimuli continues to develop into late childhood (Burack et al. 2000; Dukette and Stiles 1996, 2001; Enns et al. 2000; Harrison and Stiles 2009; Poirel et al. 2008; Porporino et al. 2004; Scherf et al. 2009). Enns et al. (2000; Burack et al. 2000) also suggested a longer developmental progression for grouping than for individuation abilities. Other studies, on the other hand, showed longer developmental progression for local processing (e.g., Mondloch et al. 2003).

Kimchi et al. (2005) systematically examined the development of the perception of hierarchical structure from childhood to young adulthood, by comparing the performance of five- to fourteen-year-old children and young adults on few- and many-element hierarchical patterns in visual search and speeded classification tasks. In the visual search task, participants searched for a globally-defined or locally-defined target (a diamond) in displays of a variable number of few- or many-element patterns (Figure 7.4a). The primary dependent variable was search rate, defined as the slope of the best-fitting linear RT function over the number of items in the display. The results (RT slopes; Figure 7.4b) show different age-related trends in search rates for global and local targets in the many- versus the few-element displays. The RT slopes for global targets in the many-element displays and for local targets in the few-element displays were essentially zero in all age groups, indicating an efficient and effortless search that did not vary with age. The RT slopes for local targets in the many-element displays and for global targets in the few-element displays were steeper and decreasing significantly between five and ten years of age, indicating an inefficient and effortful search that improved with age.

In the classification task, participants were presented with an array of five columns of few- or many-element patterns (Figure 7.5a). The patterns in the central column were similar in elements to the patterns on one side and in configuration to the patterns on the other side (incongruent displays). The task was to indicate whether the central column belonged with the patterns on the left or right side on the basis of similarity in global configuration (global classification) or in local elements (local classification). The results (Figure 7.5b) converged with those of the visual search. Five-year-olds made significantly more errors than older participants in the global classification of few-element patterns and in the local classification of many-element patterns, whereas all age groups yielded similar low error rates in the global classification of many-element patterns and in the local classification of few-element patterns. Similar age trends were evident in the RT data.

These results suggest that grouping of many small elements and individuation of a few large elements mature at a relatively early age, while grouping a few large elements and individuating many small elements develop with age, improving significantly between age five and ten and reaching adult-like levels between ten and fourteen years of age.

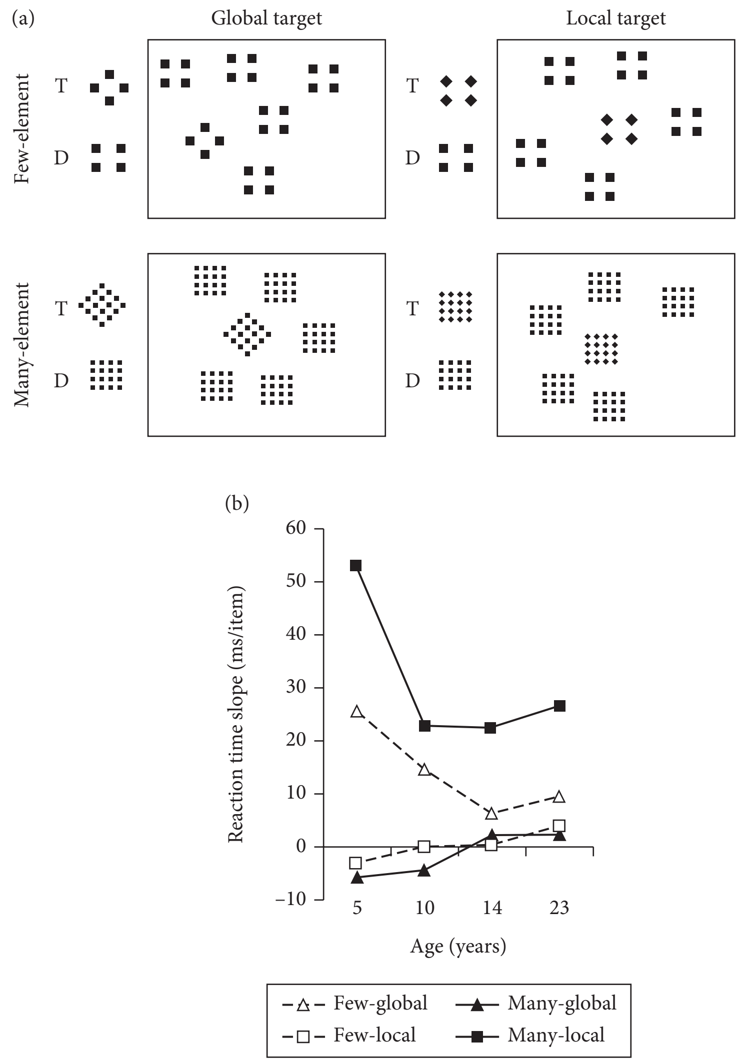

Fig. 7.4 (a) Examples of displays in the visual search task used by Kimchi et al. (2005). An example is shown for each combination of pattern (many-elements or few-elements) and target (global or local). The target (T) and distractors (D) for each example are indicated. All the examples presented illustrate display size of 6. (b) Search slopes for global and local targets as a function of pattern and age.
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These findings may help resolve some of the apparent contradictions in the developmental literature mentioned earlier. Enns et al. (2000; Burack 2000) used few-element patterns and found age-related improvements in search rates for globally-defined but not for locally-defined targets. Mondloch et al. (2003), on the other hand, used many-element patterns and found age-related improvements for local but not for global processing. Thus, depending on the nature of the stimuli used, the different studies tapped into different processes that emerge along different developmental trajectories.

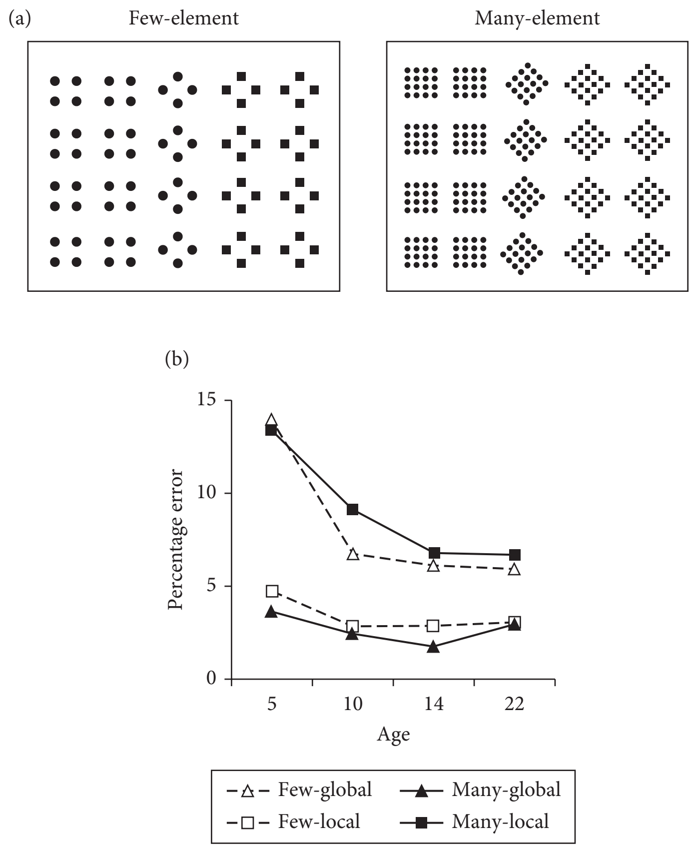

Fig. 7.5 (a) Examples of incongruent displays in the few-element and many-element conditions for the speeded classification task used by Kimchi et al. (2005). (b) Error rates for global and local classifications in incongruent displays as a function of pattern and age.

Importantly, however, the adult-like grouping of many small elements observed with the younger children in the visual search and classification tasks (Kimchi et al. 2005) may not reflect the same level of functioning as the fast and early grouping observed in adults in the primed matching task (Kimchi 1998), as suggested by the findings of Scherf et al. (2009). Using the primed matching task, Scherf et al. (2009) found age-related improvement in the ability to derive the global shape of the many-element patterns at the short prime durations that continued through adolescence. It is possible then, that different tasks tap into different levels of the organizational abilities. Children are capable of grouping elements into global configuration to a certain degree, which may suffice to support performance in the visual search and classification tasks, but when confronted with more challenging task such as primed matching under brief exposures, adult-like performance emerged only in adolescence, indicating that the full process of integrating local elements into coherent shapes to the extent of facilitating global shape identification develops late into adolescence. This long developmental trajectory coincides with what is known about the structural and functional development of the ventral visual pathway (Bachevalier et al. 1991; Gogtay et al. 2004).

The findings concerning the development of the perception of hierarchical structure converge with other findings reported in the literature, suggesting that there is a protracted developmental trajectory for some perceptual organization abilities, even those that appear to emerge during infancy (see Kimchi 2012, for a review and discussion).

Interpretation of global advantage: Levels of structure and holistic properties

Overall, global advantage is normally observed with the typical hierarchical stimuli (i.e., many-element hierarchical patterns) used in the global–local paradigm to the limits of visibility and visual acuity. A number of issues have been raised, however, concerning the interpretation of global advantage (Kimchi 1992; Navon, 2003). One issue concerns the hierarchical patterns that are the cornerstone of the global–local paradigm. Hierarchical patterns provide an elegant control for many intervening variables while keeping the hierarchical structure transparent, but the local elements of the hierarchical patterns are not the local properties of the global form, they are not the parts of the whole (Kimchi 1992, 1994; Navon 2003). The local properties of the large letter H (see Figure 7.1), for example, are not the local Hs or Ss but, among others, vertical and horizontal lines. Thus, global advantage is not an advantage of a global property of a visual object over its local properties, but rather, an advantage of properties of higher level units over the properties of the lower level units (Kimchi 1992). Somewhat different, albeit related suggestion has been made by Navon (2003): the local elements of hierarchical patterns are local constituents of a well-grouped cluster, and global advantage is an advantage of the cluster over its local constituents. This suggestion is compatible with the view presented earlier, that perceptual organization processes play a role in global advantage (Han and Humphreys 1999; Kimchi 1998; Kimchi et al. 2005).

Furthermore, the assumption that the global form and the local elements of hierarchical stimuli map directly into two perceptual levels that differ only in their level of globality, has been questioned. For example, Kimchi and Palmer (1982, 1985) showed that many-element patterns (like those typically used in the global-local paradigm) are perceived as global form associated with texture, and the form and texture are perceptually separable. Patterns composed of few, relatively large elements, on the other hand, are perceived as a global form and figural parts, and are perceptually integral. Pomerantz (1981, 1983) distinguished between patterns in which only the position of the elements matters for the global form and patterns in which both the position and the nature of the elements matter, arguing that the local elements in Navon's hierarchical stimuli are mere placeholders. If the local elements of many-element patterns serve to define texture or are mere placeholders, then they may not be represented as figural units, and consequently, faster identification of the global form than the local form may be accounted for not by its level of globality but by a qualitative difference in identification of a figural unit versus a textural molecule. However, this argument is somewhat weakeded by the finding that an earlier representation of the global form of many-element hierarchical stimuli is followed by a spontaneous individuation of the local elements (Kimchi 1998), and the finding that element heterogeneity in many-element hierarchical stimuli has no effect on global/local advantage (Navon 2003).

Another, not unrelated issue is that the difference between global and local properties, as operationally defined in the global-local paradigm, may be captured in terms of relative size, and relative size alone rather than level of globality, may provide a reasonable account for the observed global advantage with hierarchical patterns (Navon and Norman 1983). Navon (2003, p. 290) argued that globality is inherently confounded with relative size, that it is a fact of nature that relative size is "an inherent concomitant of part–whole relationship." This is indeed the case if global properties are properties of a higher level unit. For example, the shape of a face is larger than the shape of its nose. Yet, if global properties are meant to be properties that depend on the relationship between the components, as the theoretical motivation for the global precedence hypothesis seems to imply (e.g., Navon 1977, 2003), then the essential difference between global properties and component properties is not captured by their relative size. To distinguish, for example, squareness from the component vertical and horizontal lines of a square, or faceness from the facial components of a face, based only on their relative sizes would miss the point.

Thus, a refinement of terminology is called for between *global properties*, which are defined by the level they occupy within the hierarchical structure of the stimulus, and *holistic/configural* properties that arise from the interrelations between the component properties of the stimulus (Kimchi 1992, 1994). Evidence concerning the primacy of holistic properties and the distinction between holistic properties and global properties is presented in the next sections.

The primacy of holistic properties

The Gestaltists claim that wholes have properties that cannot be derived from the properties of their components is captured in modern psychology by the notion of holistic or configural properties. Holistic/configural properties are properties that do not inhere in the component parts, and cannot be predicted by considering only the individual component parts or their simple sum. Rather, they arise on the basis of the interrelations and interactions between the parts. Examples are symmetry, regularity, and closure (Garner 1978; Kimchi 1992, 1994; Pomerantz 1981; Rock 1986; Wagemans 1995, 1997). Thus, for example, four simple lines that vary in orientation can configure into a square—with a configural property of closure—or into a cross—with a configural property of intersection. Holistic properties exist along with, not instead of, component properties, and are a different aspect of a stimulus (Garner 1978). The Gestaltists' claim about the primacy of wholes finds its modern counterpart in the hypothesis about the primacy of holistic properties, which states that holistic properties dominate component properties in information processing.

Holistic primacy in visual forms. Empirical research pitting holistic against component properties using visual forms (with proper controls for differences in discriminability) has provided converging evidence for the primacy of holistic properties (see Kimchi 2003a, for a review). Lasaga (1989) and Kimchi (1994; Kimchi and Bloch 1998) investigated the relative dominance of component and holistic properties by examining whether the discriminability of the components predicts the discrimination of their configurations. They reasoned that if holistic properties dominate information processing, then, irrespective of the discriminability of the components, the discrimination between stimuli that have dissimilar holistic properties should always be easier than discrimination between stimuli that have similar holistic properties, and classification by holistic properties should be easier than classification by the components.

Consider the stimulus sets presented in Figure 7.6. Discrimination and classification performance with the four simple lines that vary in orientation (Figure 7.6a) showed that discrimination between the two oblique lines is more difficult than between any other pair of lines, and the classification that involves grouping of the horizontal and vertical lines together and the two oblique lines together is significantly faster and more accurate than the two other possible groupings (Kimchi 1994; Lasaga and Garner 1983). These simple stimuli were then grouped to form a new set of four stimuli (Figure 7.6b), which differed in highly discriminable component properties (e.g., oblique vs. vertical lines) but shared a holistic property (e.g., closure), or shared a component

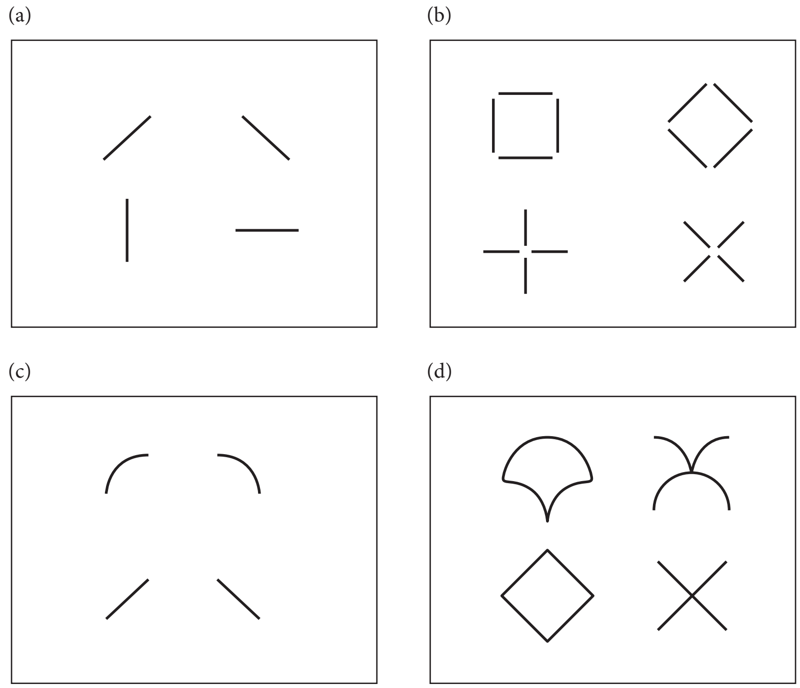

Fig. 7.6 Examples of the stimulus sets for the discrimination and classification tasks used by Kimchi (1994) and Kimchi and Bloch (1998). Four simple lines that vary in orientation (a) are grouped into the stimuli in (b). Four simple lines that vary in curvature (c) are grouped into the stimuli in (d). Note that for the stimuli in (d), configurations that share holistic properties (e.g., closure) are not, unlike those in (b), simple rotation of one another.

Parts (a) and (b) are reproduced from Ruth Kimchi, The role of wholistic/configural properties versus global properties in visual form perception, Perception, 23(5), pp. 489–504, doi:10.1068/p230489 © 1994, Pion. With permission from Pion Ltd, London www.pion.co.uk and www.envplan.com. Parts (c) and (d) are reproduced from Psychonomic Bulletin & Review, 5(1), pp. 135–139, Dominance of configural properties in visual form perception, Ruth Kimchi and Benny Bloch, DOI: 10.3758/BF03209469 Copyright © 1998, Springer-Verlag. With kind permission from Springer Science and Business Media.

property (e.g., oblique lines) but differed in holistic property (closed vs. open). The pattern of performance with the configurations was not predicted by the discriminability of their components; rather it confirmed the prediction of the hypothesis about the primacy of holistic properties: the two most difficult discriminations were between stimuli with dissimilar components but similar holistic properties (square vs. diamond and plus vs. X). Moreover, the discrimination between a pair of stimuli that differ in a holistic property was equally easy, regardless of whether they differed in component properties (e.g., the discrimination between square and plus was as easy as the discrimination between square and X). Also, the easiest classification was the one that was based on holistic properties, namely the classification that involved grouping of the square and diamond together and the plus and X together (Kimchi 1994, see also Lasaga 1989). Similar results were also observed with stimulus sets in which stimuli that shared a holistic property were not a simple rotation of each other (Figure 7.6c,d; Kimchi and Bloch 1998).

Thus, when both holistic and component properties are present in the stimuli and can be used for the task at hand, performance is dominated by holistic properties, regardless of the discriminability of the component properties. When holistic properties are not effective for the task at hand, discrimination and classification can be based on component properties, but there is a significant cost relative to performance based on holistic properties.

The primacy of holistic properties is also manifested in the configural superiority effect (Pomerantz et al. 1977; see also Pomerantz and Cragin, this volume): the discrimination of two simple oblique lines can be significantly improved by the addition of a context that creates a triangle and an arrow configuration.

Other studies have provided converging evidence for the early representation of holistic properties. Thus, Kimchi (2000; Hadad and Kimchi 2008), using primed matching, showed that shapes grouped by closure were primed at very short exposure durations, suggesting that closure was effective already early in the perceptual process. Holistic properties were also found to be accessible to rapid search (e.g., Rensink and Enns 1995).

Holistic primacy in faces. The case of faces is an interesting one. The "first-order spatial relations" between facial components, namely the basic arrangement of the components (i.e., the eyes above the nose and the mouth below the nose), is distinguished from the "second-order spatial relations"—the spacing of the facial components relative to each other. Facial configuration, or faceness, is the consequence the former, differentiating faces from other object classes. The configural properties that arise from the latter (e.g., elongation, roundedness) differentiate individual faces (e.g., Diamond and Carey 1986; Maurer et al. 2002). The dominance of the facial configuration (i.e., faceness) over the components is easily demonstrated: replacing the components but keeping their spatial arrangement the same does not change the perception of faceness. An example is the "fruit face" painting by the Renaissance artist Archimbaldo. On the other hand, the relative contribution of configural properties and component properties to face perception and recognition has been a controversial issue (e.g., Maurer et al. 2002). Some studies demonstrated that configural properties dominate face processing (e.g., Bartlett and Searcy 1993; Freire et al. 2000; Leder and Bruce 2000; Murray et al. 2000), and other studies provided evidence that facial features themselves play an important role in face processing (e.g., Cabeza and Kato 2000; Harris and Nakayama 2008; Schwarzer and Massaro 2001). However, Amishav and Kimchi (2010) demonstrated, using Garner's (1974) speeded classification paradigm with proper control of the relative discriminability of the two types of properties, that perceptual integrality of configural and component properties, rather than relative dominance of either, is the hallmark of upright face perception (see also Behrmann et al. this volume).

Global versus holistic properties

Although the terms global and holistic properties are often used interchangeably, they can be distinguished on both theoretical and empirical grounds. As noted earlier, global properties are defined by the level they occupy within the hierarchical structure of the stimulus. The difference between global and local properties (as operationally defined in the global–local paradigm) involves size: Global properties are by definition larger than local properties because the global configuration is necessarily larger than the local elements of which it is composed. The critical difference between holistic properties and component properties, however, is not their relative size. Holistic/configural properties are a consequence of the interrelations between the component properties of the stimulus.

To examine whether the distinction between global and holistic properties has psychological reality, we must dissociate level of globality (global vs. local) from type of property (holistic vs. nonholistic). With hierarchical stimuli, it is possible to construct stimuli in which different types of properties are present at the global and the local levels. Accordingly, Kimchi (1994) employed hierarchical stimuli that varied in configural (closure) and nonconfigural (line orientation)

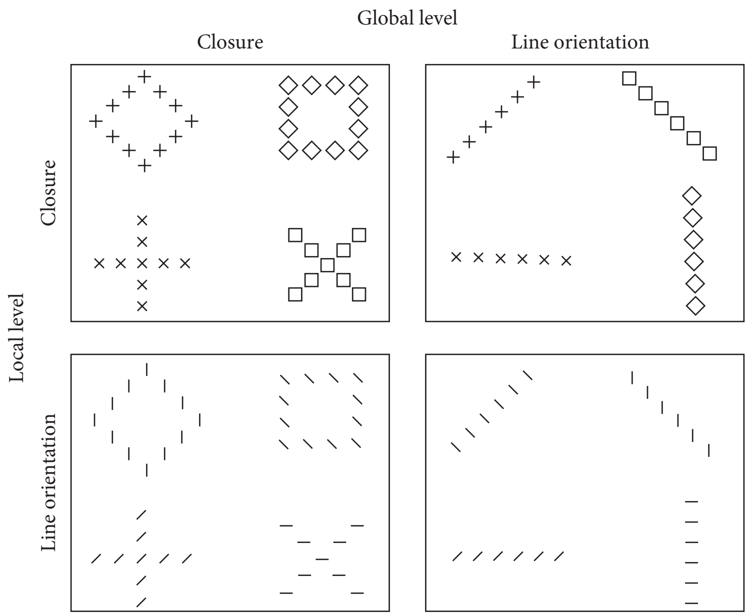

Fig. 7.7 Four sets of four stimuli each, produced by the orthogonal combination of type of property and level of structure.

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properties at the global or the local levels. The orthogonal combination of type of property and level of structure produced four sets of four stimuli each (see Figure 7.7). Participants classified each set of four stimuli on the basis of the variation at either the global or the local level of the stimuli (global or local classification task). Depending on the stimulus set, classification (global or local) was based on closure or on line orientation. The results showed that global classification was faster than local classification only when the local classification was based on line orientation; no global classification advantage was observed when local classification was based on closure.

Han et al. (1999) used different stimuli (arrows and triangles) and the typical global-local task. They found a global advantage (i.e., faster RTs for global than for local identification and global-to-local interference) for both orientation discrimination and closure discrimination, but the global advantage was much weaker for the closure discrimination task than for the orientation discrimination task. Under divided-attention conditions, there was a global advantage for orientation but not for closure discrimination tasks.

Thus, both Kimchi's (1994) and Han et al.'s (1999) results indicate that relative global or local advantage for many-element hierarchical patterns depends on whether discrimination at each level involves configural or nonconfigural properties. When local discrimination involves a configural property like closure, the global advantage markedly decreases or even disappears relative to the case in which discrimination at that level involves a nonconfigural property like orientation.

These findings converge with the findings reviewed earlier that show a relative perceptual dominance of configural properties. They also suggest that configural properties are not necessarily global or larger. Leeuwenberg and van der Helm (1991; 2013) using a different approach, also claim that holistic properties that dominate classification and discrimination of visual forms are not always global. According to the descriptive minimum principle approach proposed by Leeuwenberg and van der Helm (see also van der Helm's chapter on simplicity, this volume), the specification of dominant properties can be derived from the simplest pattern representations, and it is the highest hierarchical level in the simplest pattern-representation, the "superstructure," that dominates classification and discrimination of visual forms. The "superstructure" is not necessarily global or larger.

Concluding remarks

The vast majority of the findings reviewed in this chapter support the view of holistic dominance. This dominance can arise from temporal precedence of the global level of structure, as when the global configuration of a many-element pattern is represented before the elements are individuated (global precedence), or from dominance in information processing, as when holistic properties such as closure, dominate component properties in discrimination and classification of visual forms (holistic primacy).

In light of this evidence, a view that holds that the whole is perceived just by assembling components is hardly tenable. However, several findings suggest that positing holistic dominance as a rigid perceptual law is hardly tenable either. Early relative dominance of either the global structure or the components has been found, depending on certain stimulus factors (e.g., Kimchi 1998, 2000), configural dominance has been found with certain configurations but not with others (e.g., Pomerantz 1981; see also Pomerantz and Cragin, this volume), and the relative dominance of configural properties versus component properties has been found to depend on its relevance to the task at hand (e.g., Han et al., 1999; Pomerantz and Pristach 1989). It is also important to note that there are different kinds of wholes with different kinds of parts and part-whole relationships. Consider for example, a face with its eyes, nose, mouth, and a wall of bricks. Both are visual objects—wholes—but the eyes, nose and mouth of a face are its component parts, whereas the bricks in the wall are mere constituents. Furthermore, there are weak or strong wholes, mere aggregation of elements or configuration that preempt the components (see Rock 1986). To complicate things even further (or rather, shed some light), a distinction has been made between global versus local in terms of relative size and levels of representation in a hierarchical structure and between holistic/configural versus simple/component properties (Kimchi 1992, 1994). It is likely, therefore, that global precedence characterizes the course of processing of some wholes but not of others, and that the processing of some wholes but not of others is dominated by holistic properties; it is also the case that the processing of some wholes (e.g., faces) is characterized by the integrality of configural and component properties.

In a final note, it is appropriate to comment about holistic dominance and the logical relations between parts and wholes, or between components and configurations. Components can exist without a global configuration, but a configuration cannot exist without components. Therefore, components are logically prior to the configuration of which they are part. Similarly, if holistic/configural properties do not reside in the component properties but rather emerge from the interrelations among components, then logic dictates the priority of the components. Holistic dominance is also not easily reconciled with the classical view of visual hierarchy in the spirit of Hubel and Wiesel (1968; Maunsell and Newsome 1987). However, the logical structure of the stimulus does not necessarily predict processing consequences at all levels of processing (Garner 1983; Kimchi 1992; Kimchi and Palmer 1985), and the anatomical, structural aspects of the hierarchy of the visual system can be distinguished from the temporal, functional aspects of it, taking into account the extended connection within cortical areas and the massive feedback pathways (e.g., Maunsell and Essen 1983). It is possible, for example, as suggested by Hochstein and Ahissar's (2002) reverse hierarchy theory, that implicit, nonconscious, fast perceptual processing proceeds from components to configurations, whereas, conscious, top-down, task-driven attentional processing begins with configurations and then descends to components/local details if required by the task.

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