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The Orthogenetic Principle in the Perception of "Forests" and "Trees"?

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This study explores possible links between ontogenetic and microgenetic change (Werner, 1948, 1957) in the perception of stimuli with multiple levels of structure. Visual search for targets defined by local versus global structure was examined in observers aged 6, 8, 10, and 22 years. Perceptual access to each level of structure was varied by using pattern elements of same (easy) or opposite contrast polarity (hard); attentional processes were isolated from sensory processes by varying the number of display items. The results showed large improvements with age in search rates for global targets, with search rates for local targets being more constant over age. This pattern held regardless of whether perceptual access to a target was easy or hard. These results support the view that the perception of local and global structure involves different underlying processes.

KEY WORDS: Visual search; local perception; global perception; perceptual development; othogenic principle; visual attention.

The orthogenetic principle, that development proceeds from an initially undifferentiated state to one of increasing specialization, and finally to the coordinated integration of specialized components (Werner, 1948, 1957), is a central tenet of modern developmental theory. Its legacy is evident in current research on human development, including that concerned with brain anatomy and physiology (Johnson & Vacera, 1996), perceptual classification (Kemler, 1989; Smith, 1989), conceptual categories (Smith, 1991), speech and language acquisition (Werker, 1991), and psychopathology (Burack, 1997; Cicchetti, 1984; Cicchetti, Rogosch, & Toth, 1997).

In many studies of development, change is typically viewed in relation to performance of children at different ages, referred to by Werner as the study of ontogenesis. However, one facet of the orthogenetic legacy that appears to be largely forgotten is Werner's (1948, 1957) argument that the dialectical patterns of change in development can also be observed in comparisons of the perception of adult observers viewing stimuli of varying durations. To convey the theoretical link to processes of development, Werner referred to the analysis of the emergence of a percept over time as microgenesis.

Werner (1957) illustrated the concordance between the ontogenic and microgenic approaches by comparing the pattern of verbal responses of younger and older observers to Rorschach stimuli (ontogenesis) with the pattern of verbal responses of adults viewing the same stimuli following presentations of various exposure durations (microgenesis). He found that increasing the exposure duration of a stimulus from 10 milliseconds to 10 seconds resulted in patterns of different verbal responses among adults that mirrored those of observers between the ages of 3 and 10 years when the stimuli were presented for unlimited viewing. Werner saw these similar patterns as support for the orthogenetic principle, that there is an underlying unity in the patterns of change seen in perceptual development and in the emergence of a percept. In both cases, representations moved from

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a state of global diffusion to those that are more analytic, leading ultimately to representations that integrate the part and the whole.

The pursuit of possible links between the development of the organism on a scale of years in concert with the emergence of a percept on the scale of milliseconds was largely abandoned as researchers in each of the fields focussed on issues that were sufficiently difficult in their own right. Explicit comparisons across fields were abandoned, perhaps because they might only muddy the waters. In this paper, we propose that the time may now be ripe for further comparisons of the sort envisaged by Werner (1948), specifically in the area of perceptual organization. We are generally optimistic that attempts of cross-fertilization are mutually beneficial (e.g., Enns & Burack, 1997), but we are especially optimistic when the two fields have as much in common as do the literatures on perceptual development and perceptual organization.

THE STORY OF THE FOREST AND THE TREES IN TWO LITERATURES

The Microgenic Story

The fundamental question of whether the ''forest'' or the ''trees'' of a visual pattern are seen first is an almost cliched question in research on visual perception. According to the theory of global precedence (Navon 1977, 1981a, 1981b, 1983; Wertheimer, 1925/1955), global aspects of a display (sometimes called configurational or gestalt aspects) are perceived first. This position is usually pitted against the structuralist viewpoint (Titchener, 1909; Treisman & Gelade, 1980), in which the perception of the local aspects (sometimes called component or featural aspects) must occur before the structure of the larger picture can be acquired. In the literature there is strong evidence for both perspectives, suggesting that the question as originally posed may not be the right one to ask. The emerging consensus is that the structural level first experienced by the observer is dependent on a number of specific stimulus and internal factors (Coren, Ward, & Enns, 1999; Kimchi, 1992; Uttal, 1994).

Although these factors may often, or even generally, conspire under everyday viewing conditions to result in the initial experience of global precedence (forest before trees), the visual centers are not necessarily inherently biased in favor of global processing. For example, smaller display items and dense spacing of visual elements seem to favor global precedence, whereas larger displays and increased inter-element spacing favor local precedence (Enns & Kingstone, 1995; Kimchi, 1992; Kinchla & Wolfe, 1979; Lamb & Robertson, 1990; Martin, 1979; Navon, 1983). This is consistent with the view that the sensory processing of a visual pattern begins at a certain scale, such that patterns appropriately tuned to that scale will be analyzed more quickly than patterns that are either finer or coarser in scale.

In addition, the observer's attentional state appears to be a critical variable, as the level of the stimulus (local vs. global) immediately preceding the current stimulus can be a better predictor of performance than the objective size or spacing of the stimuli (Ward, 1982, 1983). Accordingly, the focus of research in this area changed from the question of ''which comes first?'' to the more informative question of how sensory (bottom-up) factors interact with internal (top-down) mechanisms to bias perception toward one or the other level in any given situation. For example, in a recent study (Austen & Enns, in press) observers searched through a display of compound letters that rapidly alternated between two frames. Whereas the distractor letters did not change from frame to frame, the target was a single letter that alternated either at the local or the global level. The most important finding was that observer's sensitivity to change was dependent on an interaction between their bottom-up attentional focus (a single letter which could be fully attended versus distributed attention was over multiple items) and their top-down attentional set (change was expected to occur most often at either the local or global level). Under full attention to a single item, sensitivity to change was completely consistent with the biasing condition, such that local changes were detected most rapidly and accurately when changes were most likely to occur at that level. However, when attention was distributed over multiple items, sensitivity was always greater for change at the global level.

The Ontogenic Story

Developmental studies of the perception of global and local structure were also common during the past 30 years (e.g., Gibson, 1969; Kemler, 1989). The early consensus seemed to be that the perception of developing children moved along a global-to-local trajectory. For example, proponents pointed to the

eye scanning patterns of infants viewing line drawings, which tend to be fixated on external contours early in life, only later including interior details and active comparisons between external and interior contours (Fantz, 1961; Ghim & Eimas, 1988; Quinn & Eimas, 1986; Zaporozhets, 1965). Researchers of post-infancy pointed to the tendency for younger children to categorize objects on the basis of their overall similarity rather than on the similarity of individual feature dimensions (Ames, Metraux, Rodell, & Walker, 1974; Gibson *et al.,* 1962; Shepp, 1978; Smith & Kemler, 1977), and to their difficulty in finding target figures hidden in camouflage (Enns & Girgus, 1985; Ghent, 1956).

However, as with the literature on perceptual organization, this commonly accepted notion of a global-local progression was called into question. Age-related patterns of performance now appear to be largely task dependent (e.g., Ward & Vela, 1986) and children and adults can perform similarly in attending to global and local attributes under appropriate conditions (Stiles, Delis, & Tada, 1991; Ward, 1988; Ward & Scott, 1987). The age differences observed in a perceptual task do not indicate a general tendency to see either the larger gestalt or the local details first, but rather reflect the inability of young children to tailor their attentional strategy appropriately to the formal demands of the task (e.g., Enns & Girgus, 1985).

From a developmental perspective, then, posing the question as one of global versus local primacy is as unsatisfactory here as it is in the literature on perceptual organization. Framing a developmental question solely in terms of temporal primacy ignores other equally important aspects of the developmental trajectory (Aslin, 1985; Aslin & Smith, 1988). For example, understanding development includes knowing when something begins to emerge, the rate of change, and the ultimate level of functioning that will be attained. As Aslin and others note, there is no necessary link between the initial appearance of an aspect of functioning and either the rate of change or the ultimate level of functioning. Certain functions may be observed early, develop alone or in concert with other functions into a complex entity, and continue to change for some time. Others, in contrast, may emerge much later in development, but change little, and reach optimal levels in relatively little time.

The perception of global versus local visual structure may reflect some of these subtleties. Certain aspects of perceived visual structure may appear in development before other aspects. Yet, these early appearing aspects are not necessarily the same aspects that develop the most rapidly. Consider, for example, the multiple levels of visual structure in a hierarchical pattern such as a face. At the most crude, and in some sense ''global,'' level of description, a face can be described and seen as a blob of matter that has spatial and temporal contiguity. Becoming more ''analytic,'' we can describe a face as consisting of some subset of highly likely features such as eyes, ears, and mouth. If we begin to examine the invariant spatial relations that exist among these features, we will be well on the road to having an ''integrated'' description of parts, whole, and their relations.

From a developmental perspective, young infants likely perceive the spatiotemporal contiguity of a stimulus such as a face before they are able to perceive its component parts (Cohen & Younger, 1984, Spelke & Breinlinger, 1993). This occurs because clear perception of the parts requires, by definition, a particular level of high resolution acuity that only develops during the first year of life (Coren *et al.,* 1999). However, this should not be taken to imply that global precedence will be the rule in the rest of perceptual development with regard to face perception. Once the visual system is sufficiently developed to permit clear perception of local features such as eyes, ears, and mouth (i.e., local structure), there may indeed be a much longer developmental progression concerned with the perception of the spatial relations among parts (i.e., global structure).

The perception of global and local visual structure may be one of these cases. Certain aspects of visual function related to the perception of global structure may appear in development before there is evidence of the perception of local structure. This could come about, for example, if the sensory apparatus that was in place early in life favored a global analysis of a given stimulus. Seeing the local details of the same stimulus might require more active mechanisms of selective attention that could be attained by older but not a more stimulus-bound younger observer. In an older observer, one might expect greater attentional control over the level of visual analysis, to the extent that a local analysis guided by attentional mechanisms might even outperform (in both speed and accuracy) the obligatory sensory analysis, which on its own would favor the global level. However, an optimal level of local analysis might be attained at a certain age, while global processing would continue to evolve in an increasingly complex manner. This is only one of many possible scenarios of developmental change in the perception of visual structure.

As a first step to unravelling these threads, we investigated age-related differences in perceived structure, using a methodology with which sensory factors are isolated from attentional ones.

USING THE VISUAL SEARCH TASK TO ILLUMINATE GLOBAL-LOCAL PROCESSING

Enns and Kingstone (1995) used a visual search task to distinguish attentional from sensory-based processes in the perception of stimuli with a hierarchical structure. In a visual search task, participants try to detect the presence of a target in a display as rapidly and accurately as possible. Response times (RTs) on trials in which the target is correctly detected are examined as a function of the total number of visual items (target and distractors) in the display. Typically, RT increases monotonically with display size. The intercept of this function is conventionally considered a measure of time needed to complete the sensory and motoric operations of the visual search task that are common to all trials regardless of display size. The slope of the RT function over display size is taken to reflect the cost associated with attending to a larger number of potential targets and the process of selecting the target item from the larger set (Duncan & Humphreys, 1989; Sternberg, 1969; Treisman & Gelade, 1980; Wolfe, Cave, & Franzel, 1989). Thus, baseline RT is an index of sensory processes and RT slope is an index of attention-limited processes.

In the experiment that was the basis for the present study (Enns & Kingstone, 1995, Experiment 4), each visual item consisted of four dots that could be arranged spatially to comprise one of four different configurations, as shown in Fig. 1. The four dots could be arranged either in a straight vertical column (labeled Distractor in Fig. 1), or to form an oblique line (labeled Dual Target in Fig. 1). When these types of items were used as distractors and targets, observers were able to effortlessly detect the targets and the slope of the resulting RT function over display size was correspondingly flat. The more informative conditions, with regard to local and global processes, involved the two targets labeled Local Target and Global Target in Fig. 1. Here the spatial configurations of the four dots in each item differed from the vertical distractor item only at the level of the upper and lower dot pairs (Local Target) or in the relations between vertically oriented dot pairs (Global Target). The extent to which search was more difficult in either of these conditions than in the Dual condition was taken as a measure of the time required to detect each level of visual structure.

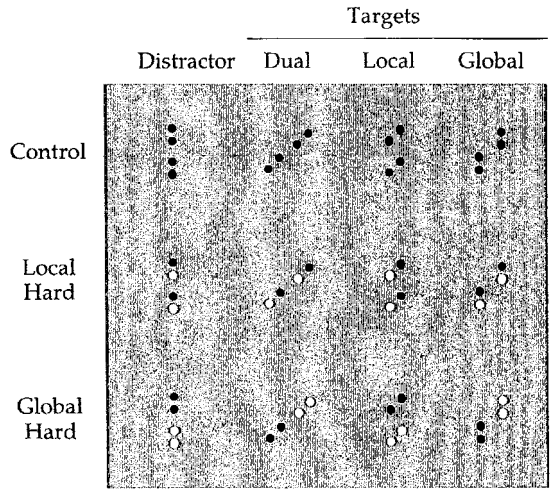

Fig. 1. Items used in the visual search tasks.

The primary finding was that variations among stimulus factors, such as element size and item density, had qualitatively different effects on search performance for local than for global targets. Specifically, these factors resulted in baseline differences in search time; increased size and density were related to faster search times for local targets, but slower search times (decreased RT slope) for the global targets. In keeping with the logic of the visual search methodology, this pattern of results indicated that the perception of the global structure of the items was influenced to a greater extent by an attention-limited stage of processing than was the perception of local structure. The hypothesis that a "grouping" operation was the specific attention-limiting factor was confirmed in a final experiment where the difficulty of grouping was varied using dots in each item that were either the same or of opposite contrast polarity. These findings, based on a microgenic analysis, are at least suggestive of a specific ontogenetic pattern or trajectory: local pattern grouping in a developmental study should reseamble adult-like performance earlier than global pattern grouping. This was the specific orthogenic hypothesis of the following study.

A DIRECT COMPARISON OF ONTOGENESIS AND MICROGENESIS

We examined the performance of four different age groups (6, 8, 10, and 22 years) on a version of the

Enns & Kingstone (1995) visual search task (Burack, Enns, Iarocci, Randolph, in press). Twenty participants were tested in each group. There were two design features that were critical to our goals. One was that each display item consisted of two different levels of visual structure: one level involving the orientation of pairs of dots that were nearest neighbors, and the second involving the orientation of dots over longer distances. This permitted a separate examination of the sensitivity of observers to local and global grouping factors, as shown in Fig. 1.

The second design feature involved a manipulation of level discriminability. In the Control condition, all the dots were black. In the Local Hard condition, each couplet consisted of both a white and a black dot, thereby rendering the local level of orientation more difficult to see. In the Global Hard condition, one of the couplets was white and the other black, thereby making the global level of orientation less salient. These manipulations provided a full range of search task difficulty, ensuring that the analysis of visual search for local versus global grouping would not be confounded by general differences in the ease with which a given level of structure could be accessed.

As with all studies based on RT measures of observers in these age groups, we expected age-related improvements in baseline RT, resulting from improvements with age in motor planning and execution (Wickens, 1974). However, the primary question was whether age-related improvements in visual search rate (RT slope) would be different for targets defined by local versus global grouping. Age-related changes in visual search rate that are larger for global than for local targets would be consistent with the interpretation that local grouping involves simpler and more automatic visual processes than global grouping (Enns & Kingstone, 1995; Trick & Enns, 1997).

The participant's task was to detect a target item with an oblique orientation among 1, 7, or 13 other vertically oriented items. One oblique target was present at either the local, the global, or both levels on each trial; the task was simply to indicate with a key press whether it was present on the left or the right side of the display. To make the task as appealing and as clear as possible to children, all participants were told a story about soldiers guarding a palace. The instructions were to press one key with the left hand when a target (an item with a slanting part) was detected on the left side of the screen, and to press a right key when it appeared on the right side. Examples of each of the three types of possible targets were shown to observers on a card and they were told that each type would appear equally often.

This task was performed very accurately by participants in all age groups, with mean accuracy differing only by 4% between the groups (94%, 98%, 98%, and 96%, respectively for 6, 8, 10, and 22 year olds). This high degree of accuracy in the search task, along with no discernible age trends in statistical analyses of the accuracy data, indicates that differences in RT can be attributed to relative differences in the speed with which the underlying perceptual processes were accomplished.

An analysis of the baseline RT (mean correct RT for a display size of 2) showed, as expected, that the overall speed of response in this task decreased significantly with age, with significant differences occurring both between 6 and 8 years and again between 8 and 22 years. A second expected result in the analysis of baseline RT was that responses in the control task were significantly faster than in either the local hard or global hard task. This was what we had intended with our manipulation of level discriminability. Finally, we observed the expected interaction that search for Local targets was slower than for global targets in the local hard condition, and that search for global targets was slower than for local targets in the global hard condition. This confirmed that our experimental manipulation of contrast polarity had the intended effects.

With these preliminary analyses in place to confirm the validity of our main measure of performance (RT) and our experimental manipulations (local versus global grouping difficulty), we were able to turn to the central analysis of this study: How does search for local and global targets change with age? Mean correct RT slope (search rate in ms per item) is shown in Fig. 2 for each of the three search conditions. As can be seen, by comparing the rate of change in RT slope over age in Fig. 2, the largest age changes occurred for global targets, much smaller changes occurred in local target search over age, and the smallest changes were seen in search for the dual targets.

These observations were confirmed in an analysis of variance, which indicated a significant statistical interaction between age of participant and the type of search target. Individual statistical tests for each of the three target types told the same story: RT slopes decreased significantly with age for global targets in each of the three search tasks, they decreased significantly for local targets only between 6- and 8-

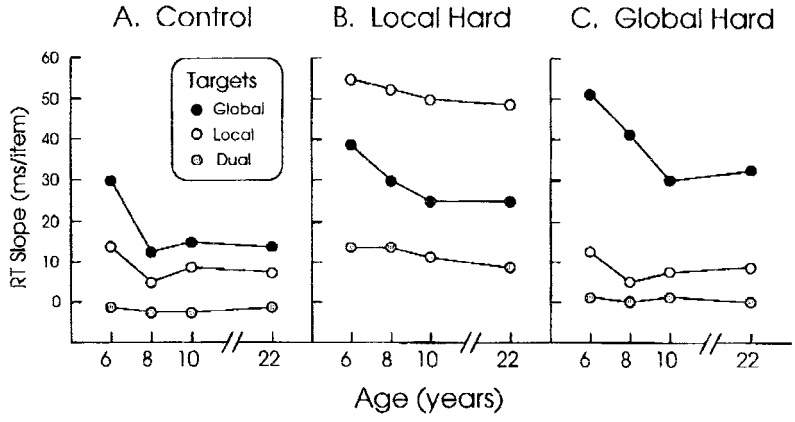

Fig. 2. Mean rates of visual search (RT slope over display size, expressed in ms per item) as a function of age. (A) Control task: All dots were black. (B) Local Hard task: Nearest dot neighbours were opposite in contrast. (C). Global Hard task: Pairs of dot clusters were opposite in contrast.

years of age in one of the three tasks (global hard), and age was not a significant factor in search for dual targets in any of the three tasks.

IMPLICATIONS OF THE FINDINGS FOR ORTHOGENETIC RESEARCH

Consistent with Werner's orthogenetic principle, the findings presented here are evidence of the ontogenetic development of perceptual organization that is consistent with previously found patterns of microgenic development. The age-related trends in visual search rates among children mirror Enns and Kingstone's (1995) findings with adults that the visual perception of global attributes of a hierarchically organized pattern requires an attention-demanding grouping process that is more difficult than that required for the grouping of local attributes. When the target item differed only in its local orientation from the distractor items, search rates differed little between younger and older observers. This was true for both relatively easy (Control) and difficult (Local Hard) tasks. Conversely, when the target item differed only in global orientation from the distractor items, search rates were significantly slower for younger as compared to older observers both for search tasks that were relatively easy for all observers (Control) and for search tasks that were relatively hard (Global Hard).

The identification of this developmental trend at more than one level of task difficulty is important, because it precludes a common criticism of developmental studies, namely, that age trends are simply "piggybacking" on the single underlying dimension of general task difficulty. Moreover, this finding also strengthens the argument that there are separate mechanisms for grouping at the Local versus global level. With only a single mechanism, age effects would be seen as a direct result of increasing task difficulty, not as a consequence of the nature of the stimulus, independent of task difficulty.

We take these findings therefore as evidence of a link between age-related changes in the perception of visual structure and the role of attention in level precedence effects. The effect of the manipulations relevant to lower-level grouping mechanisms (in this case, ease of grouping at the local level) was similar for all observers, regardless of age. Conversely, the influence of manipulations relevant to higher-level grouping processes (in this case, ease of grouping at the global level), were greater for the younger observers, who have less control over these processes, than for the older observers (see reviews by Enns, 1990; Plude, Enns, & Brodeur, 1994).

CONCLUSION

A primary motivation of this research was to test, within an orthogenic framework, the hypothesis that the perceptions of local and global structure in compound stimuli are accomplished by different means (Enns & Kingstone, 1995). This claim was originally based on the differential sensitivity of visual search for locally and globally defined items in

relation to stimulus factors such as display density, visual size, and contrast similarity. From this perspective, the perception of local structure appeared to be determined primarily by lower-level or sensory factors, whereas the perception of global structure was more heavily influenced by attentional factors.

In the present study, we found that search for locally and globally defined items was also differentially sensitive to developmental status. These findings are therefore convergent evidence for an underlying orthogenetic principle (Werner, 1948, 1957) in perceptual organization. However, it is equally important to note that these results are not simply a reaffirmation of the well-worn orthogenetic theme that development proceeds in a global-to-analytic-to-integrated course. Indeed, our conclusions are considerably more fine grained. Following the logic inherent in the orthogenetic approach, we initially identified an important theoretical construct that differed between our various observer groups: the control of attention to influence visual perception develops with age in childhood. Second, we used a behavioral testing paradigm to measure separately aspects of sensory processing from those of attentional processing. Third, we compared the results of a microgenic study of perceptual organization (Enns & Kingstone, 1995) with the results of an ontogenic study (the present study) using the same measurements. We found that the separate visual operations identified in perceiving the local and global structure of an item for adults were also separable operations in understanding developmental change in perceptual organization. Accordingly, the microgenic and ontogenic findings are convergent evidence of the orthogenetic principle.

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