Age Differences in Visual Search for Compound Patterns: Long- Versus Short-Range Grouping

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Visual search for compound patterns was examined in observers aged 6, 8, 10, and 22 years. The main question was whether age-related improvement in search rate (response time slope over number of items) was different for patterns defined by short- versus long-range spatial relations. Perceptual access to each type of relation was varied by using elements of same contrast (easy to access) or mixed contrast (hard to access). The results showed large improvements with age in search rate for long-range targets; search rate for short-range targets was fairly constant across age. This pattern held regardless of whether perceptual access to a target was easy or hard, supporting the hypothesis that different processes are involved in perceptual grouping at these two levels. The results also point to important links between ontogenic and microgenic change in perception (H. Werner, 1948, 1957).

Most visual patterns can be organized perceptually at different scales. For instance, when looking at a group of human faces, a person's visual attention may be directed to the individual features of one face (e.g., eyes or mouth), to the relations between features (e.g., eye-to-eye or eye-mouth distance), or even to the relations between the various heads in the crowd. The terms local and global are convenient terms that are used to mark relative locations along this organizational continuum.

In this study we asked whether developmental change in the ability to organize a visual pattern at different scales follows the same developmental trajectory or whether there might be separate developmental paths for perceptual organization at local and global levels. The immediate impetus for the study is both theoretical and methodological. The theoretical motivation derives from a long-standing debate in the literature regarding the relative simplicity of the task permits the testing of participants over a wide range of ages and attentional abilities.

The stimuli used in this study were compound items designed in keeping with the logic of previous studies of global-local perception (Navon, 1977, 1981a, 1981b, 1983; see Figure 1). Specifically, a target pattern can be drawn at a global level independently of whether it is drawn at a local level. The present patterns are unique in that the spatial distance among elements in a perceptual group (at either the local or global level) can be systematically controlled. Because of this, we refer to these levels with the more precise terms, short-range and long-range grouping, respectively. Among adults, the pattern of performance for short- versus long-range grouping parallels that obtained from traditional stimuli, such as global squares made up of local triangles and vice versa (Enns & Kingstone, 1995).

Developmental Change in Global and Local Processing

The idea of fundamental differences in the perception of global and local structure has a long history in the developmental literature (for reviews see Gibson, 1969; Kemler, 1983). One popular early view was that the perception of developing children moves along a global-to-local trajectory. For example, eye scanning patterns of infants indicate fixation on external contours of objects early in life, with fixations on interior details and active comparisons made between external and interior contours several months later (Fantz, 1961; Ghi & Elmas, 1988; Quinn & Elmas, 1986; Zaporozhets, 1965). Others have reported that newborns (Slater, Mattock, Brown, & Brenner, 1991) and 3-month-old infants (Bhatt, Rovee-Collier, & Shyi, 1994; Quinn, Burke, & Rush, 1993) are more sensitive to emergent properties of line elements than to component lines. In studies of children, age-related transitions in object categorization have also been reported, with younger chil-
children basing their judgments on overall similarity, and older children basing theirs on the similarity of specific object features (Ames, Metraux, Rudell, & Walker, 1974; Gibson, Gibson, Pick, & Osser, 1962; Smith & Kemler, 1977; Younger & Fearing, 1999). Older children were also generally more adept at finding targets hidden in camouflage (Enns & Girgus, 1985; Ghent, 1956).

However, the notion of one-way progression has not been supported unequivocally. For example, contrary to the global-to-local hypothesis, infants younger than 3 months of age are able to show habituation to the individual elements of a pattern (e.g., lines, animal body parts), but it is not until 7 months of age that they are able to respond on the basis of the relations formed by the elements such as angles and whole animals (Cohen, 1998). Evidence from older children also indicates that age-related patterns of global and local performance can be task dependent; children of all ages are able to perform similarly with regard to global and local attributes under appropriate conditions (Stiles, Delis, & Tada, 1991; Ward, 1988; Ward & Scott, 1987; Ward & Vela, 1986). The specific strategy adopted can be influenced both by manipulations of stimulus accessibility (e.g., increased intensity) and by task demands (e.g., instructions to attend only to one level; Freeseman, Colombo, & Coldren, 1993; Stiles et al., 1991; Ward, 1988; Ward & Scott, 1987). Consequently, age differences observed on these tasks are not always interpreted as a tendency to see either the larger Gestalt or the local details but rather as an inability of young children to appropriately tailor their attentional strategy to the demands of the task (Enns & Girgus, 1985; Tada & Stiles, 1996).

The developmental literature, therefore, now includes considerable evidence of perceptual analysis at multiple levels of structure. This literature supports the notion that the relative contribution of any given level in the control of behavior can be influenced by a variety of bottom-up (stimulus driven) and top-down (attentional) factors. However, the question of age differences in the cognitive difficulty of attending to one level or the other remains unresolved. We attribute the lack of an answer to this question to methodological shortcomings: Previous paradigms did not permit systematic control over the relative ease of perceptual access to information at each level. For example, the baseline accessibility of any specific patterns used to measure local and global perception (e.g., large shapes made up of different smaller shapes) is unknown for observers of a given age.

The Role of Attention in Global–Local Perception

In visual search tasks, participants try to detect and respond to the presence of a target in a display as rapidly and accurately as possible. Correct response times (RTs) to a target are examined as a function of the total number of visual items in the display (the target plus distractors). Typically, RT increases linearly with display size. The RT in the smallest display size is conventionally used to measure the 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 reflects the costs 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, 1994, 1998). As such, RT slope is a convenient index of attention-limited processes in search.

In a study by Enns and Kingstone (1995) of visual search, each potential search item consisted of four dots arranged to constitute one of four different configurations (see Figure 1). The four dots could be arrayed either in a straight vertical column (labeled *distractor* in Figure 1) or in an oblique line (labeled *dual* in Figure 1). When these items were used as distractors and targets, respectively, observers were able to detect the target effortlessly, and the slope of the resulting RT function over display size was correspondingly flat. The more informative conditions involved the targets labeled *short range* and *long range* in Figure 1. The spatial configurations of the four dots in each item differed from the vertical distractor item with regard either to the positioning of the dots within the dot pairs (short range) or to the positioning between the dot pairs (long range). The extent to which search was more difficult in each of these conditions than in the dual condition was taken as a measure of the time required to detect each level of structure.

Among adult observers, variations in element size and item density affect search for short- and long-range targets in qualitatively different ways (Enns & Kingstone, 1995). These stimulus factors tend to influence baseline RT in search for short-range targets, whereas they influence RT slope in search for long-range targets. This suggests that perception of the long-range groupings is more dependent on an attention-limited stage of processing than is the perception of short-range groupings. However, groupings can be made relatively more demanding of attention either by the short or the long range by using dot elements that are either the same or opposite in contrast polarity. Dots within groups that are opposite in contrast polarity lead to increased RT slopes over dots of the same polarity. This hypothesis was confirmed for short-range grouping by Enns and Kingstone and was tested in the present study for long-range grouping as well.

The differential influence on short- and long-range grouping by some variables (Enns & Kingstone, 1995) is consistent with a two-stage model of visual grouping (Rensink & Enns, 1995; Trick & Enns, 1997). In the first stage, grouping is accomplished by low-level visual mechanisms that operate in parallel for all items in

![Figure 1](https://example.com/figure1.png)

**Figure 1.** Items used in the visual search tasks.
the visual field and are not influenced by higher level, and inherently serial, processes. These rapid low-level grouping mechanisms are not as extensive or sophisticated as the grouping mechanisms associated with focused attention but appear to be based on a reduced set of the traditional Gestalt laws of grouping, such as proximity and contrast similarity within a fairly small spatial neighborhood.

By comparison, the rules governing long-range grouping are potentially more sophisticated but are also more spatially limited in their operation. This seems to reflect an inherent trade-off, both in computational and neurological terms, between the spatial range over which operations can be performed and their relative sophistication (Enns & Rensink, 1992; Rensink & Enns, 1995). For example, when attention is focused, visual grouping can be based on the element proximity in 3-D space (Rock & Brosgole, 1964), the similarity of element color after color constancy mechanisms are invoked (Rock, Nijhawan, Palmer, & Tudor, 1992), and the similarity of elements that are partially occluded (Palmer, Neff, & Beck, 1996). However, the apparent cost of grouping on the basis of such sophisticated visual operations is that the grouping is only accomplished on a significantly reduced subset of items in the visual display, thereby leading to the serial inspection of multiple items.

A simple illustration of the difference between these two levels of grouping is evident in a study of rapid visual enumeration (Trick & Enns, 1997). Adult observers can count (i.e., subitize) shapes that are drawn with connected lines very rapidly, both when these shapes are presented alone in a display and when they are presented among distractor shapes. In contrast, the same shapes drawn with disconnected dots can no longer be subitized among distractors. Apparently, the perceptual grouping of elements that are physically connected can be performed by rapid parallel mechanisms, whereas the grouping of elements not physically connected is limited by the mechanisms of serial attention.

A Developmental Study of Short- and Long-Range Grouping

We examined visual search in observers of four different groups with mean ages of 6, 8, 10, and 22 years. As shown in the examples of search displays in Figure 2, all display items consisted of a cluster of four dots. The target item differed from the distractor items in that some or all of its dots were oriented obliquely, whereas all the dots in the distractor items were oriented vertically.

Two design features of the experiment were central to our goals. One was that each display item consisted of two different levels of visual structure: One level involved the orientation of pairs of dots that were nearest neighbors; the second involved the orientation of dots over longer distances. This permitted a separate examination of the sensitivity of observers to short-range and long-range grouping.

The second design feature involved a manipulation of level accessibility (see Figure 1). In the same-contrast condition, all the dots were black, making them easy to group. In the mixed-contrast within-pairs condition, each pair consisted of both a white and a black dot, thereby rendering the local level of orientation less accessible. In the mixed-contrast between-pairs condition, one of the pairs was white and the other black, making the global level of orientation less accessible. These manipulations provided a full range of search-task difficulty, ensuring that the comparison of short-range versus long-range grouping would not be confounded by overall differences in the ease of access for a given level of structure.

A left-right target discrimination task was used instead of the typical presence-absence search task. This yielded a more efficient measure of target detection (the target was displayed on each trial, rather than only on a random one half of the trials) and avoided the complications involved in interpreting responses on target-absent trials (Treisman & Gelade, 1980; Trick & Enns, 1998; Wolfe, 1994, 1998). Accordingly, a target was presented on each trial, and participants were required to indicate as rapidly as possible whether it was on the right or left side of the display. Among adults, direct comparisons of these two procedures in the same-contrast condition showed no differences in the pattern of data obtained with each procedure for trials with the target present.

As with all studies based on RT measures, we expected age-related improvements in baseline RT, resulting from improvements with age in perceptual discrimination, 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 short-range versus long-range grouping. Age-related changes in search rate that are larger...
for long-range than for short-range targets would suggest that short-range grouping involves simpler and more automatic visual processes than long-range grouping (Enns & Kingstone, 1995; Trick & Enns, 1997). This interpretation would be strengthened further if the same pattern were found at both generally easy and hard levels of task difficulty.

Method

Participants

Twenty observers were tested in each of four age groups: 6 years (M = 75 months, SD = 6 months), 8 years (M = 98 months, SD = 11 months), 10 years (M = 122 months, SD = 5 months), and 22 years (range = 18–27 years). The children were recruited from a public elementary school in the Montreal area; the adults were McGill University students who participated as volunteers. The data from 11 observers were excluded from analysis because they failed to achieve an accuracy criterion of fewer than 10% errors overall (n = 6, 3, and 2 from the 6-, 8-, and 10-year-olds, respectively).

Stimuli and Apparatus

A Macintosh computer, running Viscope software (Enns & Rensink, 1992), generated the displays and collected the data. The visual items used in the displays are shown in Figure 1. In the same-contrast condition, all dots were drawn in black on a medium gray background (every other pixel was black); in the mixed-contrast between-pairs condition, one half of the dots were white (all pixels lit), with the dots of the two pairs opposite in contrast; and in the mixed-contrast within-pairs condition, the dots within each pair were opposite in contrast to one another. In mixed-polarity items, the spatial arrangement of white and black dots was randomly chosen. Each item subtended 1.25° in overall extent, with each individual dot subtending 0.25° to prevent influences of item collinearity.

Procedure

Observers performed the visual search task while seated 50 cm from the computer screen. The task was to detect a target item with an oblique orientation among 1, 7, or 17 other vertically oriented items. A target item was present in each display; the task was simply to indicate with a keypress 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 the 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 starting pair) was detected on the left side of the screen and to press a right key when a target 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.

Participants were administered three sets of 40 experimental trials in each of the three conditions, in counterbalanced order. A set of 10 practice trials preceded each condition to ensure that observers understood all aspects of the task. These were repeated if any problems were encountered. Participants were permitted to rest between blocks, but all conditions were completed for each observer within a single testing session lasting approximately 1 hr.

Each trial began with a fixation symbol lit for 500 ms, followed by the search display, which remained visible until the observer responded. A keypress was followed by a feedback symbol (plus for a correct response or minus for an incorrect response), which served as the fixation point for the next trial. Participants were instructed to maintain fixation at the center of the screen and to respond as quickly as they could without making errors. The experimenter monitored the number of errors to ensure that the percentage of errors remained below 10%. Any participant whose error rate exceeded 10% overall was excluded from the analysis. Trials were counted as errors if the participant failed to respond within 4 s.

Results

The mean correct RTs for each of the participant groups are shown in Table 1. These data were first analyzed by analysis of variance (ANOVA), with one between-subjects factor of age (6, 8, 10, and 22 years), three repeated measures factors of condition (same contrast, mixed contrast within pairs, and mixed contrast between pairs), target (short range, long range, and dual), and display size (2, 10, and 18 items). This analysis indicated that all main effects were significant, as were two interactions involving age (all ps < .001). A significant interaction of Age X Display Size, F(6, 152) = 3.99, MSE = 147,930, p < .001, indicated that RT slopes over display size generally decreased with age. Age X Display Size X Target, F(12, 304) = 3.20, MSE = 66,855, p < .001, indicated that the differences in RT slope between various targets also decreased with age. No other interactions involving age approached significance (all ps > .10).

Because RT in visual search tasks generally increases linearly with display size (Enns & Kingstone, 1995; Wolfe, 1998), we examined the display-size effects more closely using two parameters of a linear regression line (baseline, slope) as convenient summary statistics to describe these functions. Note that the same effects were significant when we used a simple effects approach to examine the factorial ANOVA more closely. Our reasons for reporting the regression analysis over the simple effects tests were threefold. First, baseline RT and slope RT have repeatedly been demonstrated in the visual search literature to be influenced by different variables on visual search tasks (Tong & Nakayama, 1999; Wolfe, 1994). Second, the findings are communicated more simply, because a two-way interaction involving display size becomes a main effect of RT slope. Third, baseline differences in RT are expected with age, even when there is no search task, so it is important not to confound these separable effects (Trick & Enns, 1998). In the present data, linear regression lines fit the display-size effects very well for each combination of age, condition, and target (all r 2 > .91), indicating that the present results were in line with previous studies of visual search in children (Trick & Enns, 1998). However, before turning to these analyses in detail, we discuss the accuracy data, because the interpretation of RT results is contingent upon different groups of observers' performing with similar criteria concerning the relation between RT and accuracy.

Accuracy

The mean percentage accuracy for each group was very high; the largest accuracy difference between groups was no greater than 4% (M = 94, 98, 98, and 96%, respectively, for 6-, 8-, 10-, and 22-year-olds). Although these differences were significant, F(3, 76) = 4.24, MSE = 0.053, p < .01, it is important to note that the pattern across age did not point to speed-accuracy trade-offs as the underlying cause of the RT differences. The 4% increase in accur-
Table 1
Mean Correct Search Times (in Milliseconds)

<table>
<thead>
<tr>
<th>Age (in years)</th>
<th>Target type</th>
<th>Dual-display size</th>
<th>Short-range display size</th>
<th>Long-range display size</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Same-contrast RT</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>1.348</td>
<td>1.280</td>
<td>1.325</td>
<td>1.288</td>
</tr>
<tr>
<td>8</td>
<td>1.042</td>
<td>1.032</td>
<td>1.003</td>
<td>0.999</td>
</tr>
<tr>
<td>10</td>
<td>0.956</td>
<td>0.957</td>
<td>0.921</td>
<td>0.897</td>
</tr>
<tr>
<td>22</td>
<td>0.706</td>
<td>0.722</td>
<td>0.695</td>
<td>0.695</td>
</tr>
</tbody>
</table>

| Mixed-contrast within-pairs RT |                  |                          |                        |
| 6              | 1.384        | 1.491            | 1.595                    | 1.409                  |
| 8              | 1.032        | 1.192            | 1.242                    | 1.101                  |
| 10             | 0.907        | 1.011            | 1.072                    | 0.987                  |
| 22             | 0.877        | 1.010            | 1.006                    | 0.976                  |

| Mixed-contrast between-pairs RT |                  |                          |                        |
| 6              | 1.409        | 1.421            | 1.433                    | 1.368                  |
| 8              | 1.071        | 1.059            | 1.063                    | 1.086                  |
| 10             | 0.932        | 0.956            | 0.946                    | 0.955                  |
| 22             | 0.765        | 0.750            | 0.765                    | 0.764                  |

Note. RT = response time.


cracy between 6- and 8-year-olds was consistent with the faster responses of 8-year-olds; the 2% decrease between 10- and 22-year-olds indicated that the adults were only slightly more liberal in their accuracy criterion than 10-year-olds.

The ANOVA for accuracy indicated that all interactions involving age were significant or approached significance, including Condition × Age, F(6, 152) = 2.40, MSE = 0.006, p < .04; Target × Age, F(6, 152) = 21.99, MSE = 0.006, p < .07; Display Size × Age, F(6, 152) = 3.95, MSE = 0.005, p < .01; Condition × Target × Age, F(12, 152) = 2.27, MSE = 0.005, p < .01; Condition × Display Size × Age, F(12, 304) = 2.28, MSE = 0.004, p < .01; Target × Display Size × Age, F(12, 304) = 2.82, MSE = 0.003, p < .01; and Condition × Target × Display Size × Age, F(24, 608) = 2.52, MSE = 0.003, p < .001. Closer inspection of the means showed that these interactions could all be attributed to the disproportionate number of errors made by young participants searching for long-range targets in the large display sizes of the mixed-contrast between-pairs condition. Most important, this pattern was consistent with the RT data in all important respects, indicating that RT differences and interactions among groups could not be explained by speed-accuracy trade-offs.

Baseline RT

Mean correct RT in the smallest display condition is shown in the left-hand panels of Figure 3 for each of the three search conditions. This is a convenient and direct measure of RT that is independent of the search rate (RT slope over display size). These data were analyzed with ANOVA, as well as with an ANCOVA in which RT slope was entered as a covariate. The ANCOVA was intended as a check on the assumption that baseline RT intercept was statistically unrelated to RT slope in these data. The covariate was not significant (p > .20); both analyses therefore showed the identical pattern of significant results.

As expected, baseline RT decreased significantly with age, F(3, 76) = 16.90, MSE = 596,609, p < .001. Fisher’s least significant difference (LSD) tests revealed that this decrease was significant for the transition from 6 to 8 years of age (p < .05) and for the transition from 8 to 22 years of age (p < .01).

A second significant effect in the analysis of baseline RT was that of condition, F(2, 152) = 6.52, MSE = 69,487, p < .01. This indicated, as we expected, that RT in the same-contrast condition was significantly faster overall than in either the mixed-contrast within-pairs condition (by 79 ms), F(1, 152) = 11.82, p < .01, or the mixed-contrast between-pairs condition (by 64 ms), F(1, 152) = 7.17, p < .01, which did not differ significantly from one another (F < 1).

A third significant effect of baseline RT was Condition × Target, F(4, 304) = 6.46, MSE = 15,365, p < .001. This indicated that RTs to short-range targets were slower than to long-range targets in the mixed-contrast within-pairs condition (by 50 ms) and that RTs to long-range targets were slower than to short-range targets in the mixed-contrast between-pairs condition (by 47 ms). This result confirmed that our manipulation of contrast polarity had the intended effect in both mixed contrast conditions.

Although the Condition × Age interaction did not reach significance, F(6, 152) = 1.7, MSE = 69,487, p < .12, there appeared to be different age trends for the mixed-contrast within-pairs condition versus the same-contrast and the mixed-contrast between-pairs conditions (see the left-hand panels of Figure 3). These trends were examined with polynomial contrasts. Whereas the mixed-contrast within-pairs condition (Figure 3B) had both
Figure 3. Results of the visual search task in (A) the same-contrast condition, (B) the mixed-contrast within-pairs condition, and (C) the mixed-contrast between-pairs condition. Left panels: baseline response time (RT when display size was 2); right panels: search rate expressed as RT slope.
significant linear and quadratic trends (p < .05), the same-contrast (Figure 3A) and the mixed-contrast between-pairs conditions (Figure 3C) each had only significant linear trends (p < .01). A related examination of condition differences at each age revealed that only those of the adult group were significant (p < .05). This suggests that children reached adult levels of RT faster in the mixed-contrast within-pairs condition than in the others.

One interpretation of this finding, offered with caution because of the nonsignificant interaction overall, is that short-range grouping follows a different developmental progression than long-range grouping, even as estimated by RT independent of visual search. Although there seems to be a severe limit on how rapidly short-range grouping can be accomplished by all observers (the long RTs indicate that the task is difficult), this limit is reached earlier in life than it is for long-range grouping. This hypothesis deserves more careful testing in future research.

**Search Rates (RT Slopes)**

The mean slopes of the linear RT functions are shown in the right-hand panels of Figure 3. These were analyzed with ANOVA, as well as with an ANCOVA in which baseline RT was entered as a covariate. The covariate was not significant (p > .20), and both analyses showed the identical patterns of significant results.

As in the analysis of baseline RT, a significant Condition × Target interaction, F(4, 304) = 87.74, MSE = 175.09, p < .001, reflected the intended result that short-range targets resulted in slower search rates than long-range targets in the mixed-contrast within-pairs condition (52 ms/item vs. 30 ms/item), whereas long-range targets yielded slower search rates than short-range targets in the mixed-contrast between-pairs condition (39 ms/item vs. 8 ms/item).

There was also a significant interaction of Age × Target, F(6, 152) = 3.50, MSE = 198.82, p < .01. This interaction is shown in Figure 3 for each of the three search conditions. Simple effects tests revealed that only search rates for the long-range target improved significantly with age, F(3, 76) = 7.47, MSE = 410.14, p < .001. The nonsignificant age effects were as follows: for range targets were significantly slower for 6-year-olds than for targets revealed a very different pattern. Age was not a significant effect on short- versus long-range grouping. When a target differed in spatial orientation from the distractor items at a short-range level of grouping, search rates were similar for observers of all ages. However, when targets were defined by long-range grouping, search rates were significantly slower for younger than for older observers. This finding of different developmental patterns for short- and long-range grouping is consistent with the view that they rely on different mechanisms: parallel and simpler processes for short-range grouping, and serial and more sophisticated processes for long-range grouping (Enns & Kingstone, 1995; Rensink & Enns, 1995; Trick & Enns, 1997).

But to what extent is a two-process theory really necessary to explain the present developmental results? One possibility is that short- and long-range grouping are both performed by the same mechanisms but that long-range grouping is simply more difficult, thereby taxing these mechanisms to a greater extent. By this account, the different age patterns for the two tasks merely reflect a difference in task difficulty. The short-range task appears fully developed before the long-range task because the grouping mechanisms are not stressed to the same extent. However, one encounters difficulty with this view because of an important feature of the present data—namely, that the different age patterns for short- and long-range grouping can be seen at all levels of task difficulty. A single grouping mechanism predicts that short-range grouping should generally be easier than long-range grouping. Thus, if short-range grouping were made to be equal to, or more difficult than, long-range grouping, the age patterns should then be similar or even reversed. The finding of different age trends for short- and long-range grouping, despite manipulations that made the short-range task more difficult overall (see Figure 3B), is therefore strong evidence in favor of the two-mechanism hypothesis.

A second possibility is that the present manipulation of task difficulty (same vs. mixed-contrast polarity) had a differential effect on short- versus long-range grouping. For example, perhaps mixing contrast polarity within pairs of dots influenced both short- and long-range grouping, whereas mixing polarity between pairs of dots influenced only long-range grouping. In this case, using contrast polarity to vary grouping difficulty would not have the same effects on both levels of grouping. Indeed, the data provide some evidence in favor of this possibility. A comparison of the pattern of search slopes over age, between the same contrast condition (Figure 3A) and the mixed within-pairs condition (Figure 3B) shows that only the same contrast condition (Figure 3A) and the same contrast condition (Figure 3B) shows that not only is the short-range target now much more difficult for all observers to localize but that the long-range target also yields somewhat steeper search slopes. A similar comparison of the same-contrast condition (Figure 3A) and the mixed-contrast between-pairs condition (Figure 3C) indicates that only the long-range target now results in steeper slopes. Therefore, the contrast polarity manipulation may not have been pure, in that it may have influenced both types of grouping in one case and only one in the other. However, this only strengthens, rather than weakens, our confidence in the different age patterns seen for...
short- and long-range grouping, as these differences were observed despite the possibility of less-than-pure manipulations of difficulty at each level.

Finally, it is also worth noting that the differences in age trends cannot be attributed to differential requirements of attention for search involving the two types of grouping. One line of reasoning might be that only long-range grouping is demanding of attention and that because older observers are better able to manage attentional resources, this type of grouping shows the larger change over age in visual search slopes. But this account is also belied by the data. Note that the search slopes for short-range targets in the mixed-contrast within-pairs condition (Figure 3B) are steep for all observers. Given the logic of visual search analyses, this means that search was very demanding of attention for observers of all ages. Yet no age difference in search slopes was apparent. In contrast, the age trends in search for long-range targets could be seen in tasks in which search was much less demanding of attention overall (see Figures 3A and 3B).

We do not intend to imply that all single-mechanism theories of grouping are ruled out by the present data. We acknowledge that the present data are limited in that we have examined grouping in the context of one particular task (visual search), one particular difficulty manipulation (mixed-contrast polarity), and one particular set of stimuli (virtual lines made from dot clusters). Only future studies exploring a larger range of variables will be able to confirm whether a single-, dual-, or even multiple-mechanism view of grouping will be generally supported. On the one hand, a single mechanism may eventually predict the particular interactions we found here between spatial proximity and contrast polarity. However, any such theory needs to be constrained by data such as these. On the other hand, even more than two separable mechanisms of grouping may eventually be identified, as some have proposed (Rensink & Enns, 1995). In the present context, for example, support for such a position could be explored with an experiment in which three or more factors of grouping are manipulated (e.g., spatial proximity, contrast similarity, line relations). Although the finding of three or more nonparallel lines as a function of age would not in itself imply three different mechanisms, the case for multiple mechanisms would certainly be strengthened if those lines maintained their distinctive pattern over age at all levels of task difficulty.

The Perceptual World of the Child

In addition to the theoretical implications regarding multiple mechanisms of grouping (Rensink & Enns, 1995; Trick & Enns, 1997), the present findings are relevant to understanding the attentional functioning of children. First, it is notable that the present age differences cannot be attributed to differences in the stimuli, as is sometimes argued in the literature. The spatial arrangement of the stimuli was as identical as possible for the two target types in the present study; the main difference lay in the spatial distance over which the grouping was performed. Second, the present age differences in grouping are striking because the discrepancy in the spatial separation between the two levels was so minimal. These observations help to establish that there is meaningful developmental change after 6 years of age in the ability to integrate visual elements that are not in immediate proximity to each other. This may have important implications for understanding some of the controversy in the existing literature regarding whether an infant or child of a given age is sensitive to the relatively more global level of structure in a pattern. Future studies will need to examine more systematically the variable of spatial separation between components that are to be attended in any given task.

Evidence for an Orthogenic Principle?

These results also point to a possible link between changes in visual attention on two very different time scales. At a microscopic level in adult observers (where the time scale is on the order of milliseconds), search for targets defined by short-range grouping appears to involve simpler and more parallel mechanisms than search for targets defined by long-range grouping (Enns & Kingstone, 1995). At a considerably more macroscopic level (a time scale on the order of years), 6-year-olds in the present study were similar to older children and adults in their ability to search for targets defined by short-range grouping. In contrast, adultlike search performance was not seen for long-range grouping until children were 8 or even 10 years of age.

This kind of similarity over different time scales is reminiscent of Werner’s (1948, 1957) orthogenic approach to psychological research. Werner advocated a search for common principles in studying change in human development (i.e., ontogenesis), in the emergence of perception over time (i.e., microgenesis), and even in atypical human development (i.e., pathogenesis). Werner’s motivation for this approach was his belief in an underlying unity in the biological mechanisms of change, whether on a small or large scale. The mechanism was “coordinated differentiation,” which means that development always proceeds from an initially undifferentiated state to one of increasing specialization and finally to the coherent integration of specialized components.

One of Werner’s (1957) illustrations of this underlying unity involved a comparison of the verbal responses of younger and older observers to Rorschach stimuli (ontogenesis) with the pattern of verbal responses of adults viewing the same stimuli for various exposure durations (microgenesis). He found that increasing the exposure duration of a stimulus from 10 ms to 10 s resulted in changes in the verbal responses of adults that were similar to those given by observers between the ages of 3 and 10 years. In both cases, Werner noted that responses that were initially globally diffuse became more analytic with time, leading ultimately to responses that integrated the part and the whole.

In applying Werner’s (1948, 1957) orthogenic principle to contemporary research, we wish to distinguish between methodological and theoretical aspects of the principle. At the level of methodology, the present developmental data can be linked quite directly to previous microgenetic data involving similar perceptual tasks (Enns & Kingstone, 1995). However, at the level of Werner’s specific orthogenic theory, the present pattern of results is less easily reconciled with his view. Werner’s central premise was that development proceeded invariably from diffusion to differentiation to coordination. This contrasts, at least superficially, with the present finding that local visual groupings in a visual search task actually are completed developmentally before global groupings. This apparent contradiction can be reconciled in one of two ways. First, it could be argued that the developmental progression evident in this study represents not the initial transition from diffusion to differentiation but rather the later transition from differentiation...
to increased coordination of the parts within the whole. If so, then the earlier shift from diffuse globality to differentiation would only become evident if younger observers were tested or psychophysical tests were devised to probe earlier visual processes.

However, a second option is that Werner was simply wrong about the specific direction of changes in the development of perception. This possibility suggests that rather than assuming a particular developmental course a priori, one should use methodological orthogenesis to discover the underlying principles. Such a methodological orthogenesis is still premised in Werner’s (1948, 1957) belief in the underlying unity of change in biological systems; it is simply less committed to any a priori principle concerning the specific direction of those changes. This proposed shift is also consistent with the many ways in which biological change is now seen as more complex than it was in the mid-century period during which Werner wrote.

In conclusion, there are emerging parallels between the ontogenetic and microgenetic study of global-local perception. These include the abandonment of a theory premised on global precedence, along with a greater emphasis on studying the dynamic interactions between perception (what is registered) and attention (what is seen and used for action). The specific parallel seen in the present study prompts us a degree of optimism concerning the usefulness of the orthogenic framework, especially when applied as a form of convergent methodology. We believe that it is promising when the areas to be conjoined in an interdisciplinary venture have as much in common as do the literatures on perceptual development and organization.

References


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