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Developmental Trajectories of Form Perception: A Story of Attention

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The developmental trajectories of selective and divided attention were examined in relation to the processing of hierarchically integrated stimuli. The participants included children in 4 age groups (6, 8, 10, and 12 years) and a group of young adults (24 years) who completed 2 computer-based attention tasks. In the selective attention task, the participants were instructed to attend to only 1 level of analysis and ignore the other. In the divided attention task, participants were told that the target could appear at either level, and the probability that a target would appear at either the global or local level was manipulated. For both of the tasks, distinct and qualitative developmental shifts were evident both between 6 and 8 years of age and between 8 and 10 years of age. Attention to the global form developed prior to, and may have been a prerequisite of, attention to the local form. These gains in attentional control occurred in terms of selective attention, sensitivity to the probability of bias, and relative efficiency in processing global and local targets. The clear developmental trajectory is consistent with the emergent role of voluntary attention in the processing of these types of stimuli.

Keywords: selective attention, divided attention, global–local processing, developmental trajectories in attention

In an early depiction of the development of the abilities to perceive spatial patterns, Ghim and Eimas (1988) characterized young children as holistic processors. They argued that the global form is perceived prior to the local form in the development of the perceptual system and, therefore, that visual attention develops chronologically along a global-to-local trajectory. Proponents of this approach cited evidence that infants focus on external contours of line drawings and only later include interior details (Fantz, 1961; Ghim & Eimas, 1988), and that preschool aged children characterize objects on the basis of their overall similarity rather than the similarity of their component parts (Ames, Metraux, Rodell, & Walker, 1974). However, this global-to-local trajectory is not unequivocally supported in the literature, as even children as young as 2 or 3 years of age have been found to attend to both global and local attributes under certain tasks and conditions (Prather & Bacon, 1986; Vinter, Puspitawati, & Witt, 2010). Rather, the more compelling developmental differences between global and local processing might be found in more complex situations such as those elicited when processing involves competing information at the two levels. In order to address that notion, we examined the effects of competing information on the development of both global and local processing with two common attentional paradigms—a selective attention paradigm that allowed for explicit directions to attend to either one of the levels, and a divided attention task that involved implicit information aimed to bias attention to one of the levels, in a situation of competing information.

Understanding Developmental Trajectories of Global and Local Processing

Global precedence initially inferred a strictly temporal progression from global structuring toward increasingly fine-grained analysis (Navon, 1977); this strictly temporal progression was subsequently qualified when the density of the display, size of the stimulus, and specific task instructions were found to influence the relative advantage for either global forms or local shapes (e.g., Enns & Kingstone, 1995; Hadad & Kimchi, 2006; Kimchi & Merhav, 1991; Klein & Barresi, 1985; Palmer, 1977). The considerations that led to the abandonment of the notion of a pure global precedence effect in the adult literature are also relevant to a reconsideration of developmental trajectories for global and local levels of processing. Many discrepancies about these trajectories in the developmental literature depend on the specific nature of the stimuli (cf. Burack, Enns, Iarocci, & Randolph, 2000; Kimchi, 2012; Kimchi, Hadad, Behrmann, & Palmer, 2005). Scherf, Behrmann, Kimchi, and Luna (2009) found that children and adolescents, but not adults, were slower to respond to the global

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versus the local elements of the display using both Navon's (1977) traditional compound letter task and geometrically based hierarchical displays with many or few elements. They concluded that, unlike adults, the organization of the perceptual system in children is dominated by a local precedence effect. They also argued that this tendency to focus on local elements of a display continued into adolescence regardless of whether the stimuli were letters or shapes, contained many or few local elements that made up the global shapes, or were presented for long or short display times. Concordant with the idea of children's processing of local stimuli as the default process, Burack et al. (2000) highlighted that more sophisticated processes elicited by global stimuli continue to develop well after simpler processes used for local stimuli appear to mature fully. Using stimuli that involved short-range (local) and long-range (global) groupings, they found that the search rates were similar for participants from the ages of 6 years to young adulthood when the target item differed only in its local orientation from the distracter items, but found developmental improvements in search rates for globally defined targets. The finding that global targets were harder to detect than local targets was constant, regardless of task difficulty, such that the age patterns for local and global targets were maintained even when the stimuli were manipulated so that local targets were more difficult to perceive than global targets.

As in the adult literature, the developmental patterns of global–local processing are also linked to the characteristics of the elements of the stimuli, including their number and density within the hierarchical form. For example, Burack et al.'s (2000) finding of a longer developmental trajectory for global processing of stimuli across a longer spatial range compared with more local processing of shorter range spatial relations was based on a display with few items. Conversely, Mondloch, Geldart, Maurer, and de Schonen (2003) found the opposite pattern of data with earlier development of adult-like efficiencies with local elements than with global elements; however, they used displays with many items. A direct test of this claim was provided by Kimchi et al. (2005), who found an extended developmental trajectory for global, but not local, processing with figures that included few elements, and an extended trajectory for local, but not global, processing with figures that included many elements. The grouping of many small elements and the detection of few large elements both reached adult-like levels at 5 years of age. Consistent with the evidence of the multiplicity of factors associated with the primacy of global or local functioning, the findings highlight the developmental implications of the complexity of global–local perception (Kimchi et al., 2005).

The difficulties in delineating developmental trajectories of global and local processing are highlighted by Prather and Bacon's (1986) findings that children between the ages of 2 and 5 years were able to name both part and whole aspects of simple pictures, but were less likely to name both aspects of more complex pictures. These findings suggest that the ability to perceive both global and local form individually appears to be in place by 3 years of age, whereas the coordination between the levels only develops later. In another example of the advancing complexity of global–local processing with age, Vinter et al. (2010) found that 3-year-olds preferred to draw local elements of pictures or to draw global and local elements that are not linked to each other, whereas 4-year-olds began to coordinate between the global and local elements, and 6-year-olds displayed correctly integrated and coordinated pictures.

In the present study, we provided a test of Kimchi et al.'s (2005) hypothesis that the notion of developmental trajectories of global and local processing, like the concept of level precedence in the adult literature, is largely, if not entirely, contingent on the stimulus characteristics and on the type and attentional demands of the task. We designed stimuli configurations that were intermediate between those of the many (densely packed) and few (sparsely packed) item displays described and used by Kimchi et al. and Scherf et al. (2009). We chose these displays because they diminished the possibility that the findings would be primarily a function of the stimulus properties and permitted the focus to be the functions of attention in relation to hierarchical form processing. We also extended Scherf et al.'s study by incorporating a neutral stimulus, so that the target information presented at the global or local level appeared without a competing target shape at the opposing level.

Scope of the Present Study

We included both a selective attention and a divided attention task to investigate developmental trajectories of form perception. Selective attention tasks require preferential processing at one level of analysis while ignoring the other level, whereas divided attention tasks require simultaneous processing at both levels of analysis to choose the correct level for a specific response on a given trial. The inclusion of both types of attention tasks allowed for a more complete analysis of the developmental trajectories of attentional functions in relation to level of processing. For example, this permitted the consideration of the notions that divided attention tasks may be more sensitive than selective attention tasks in eliciting differences in processing style (Plaisted, Swettenham, & Rees, 1999) and that the explicit manipulation of attention may be more effective than implicit manipulations.

In both the selective and divided attention tasks, observers of different ages reported which of two shapes (a square or a diamond) was present on the given trial. All of the stimuli used in the tasks included two levels of structure; the global target was a large shape (a square or a diamond) that was made up of smaller shapes (circles, squares, or diamonds), and local targets were small shapes (squares or diamonds) that formed a larger shape (a circle, a square, or a diamond; see Figure 1). We included eight local elements in the displays, as this was intermediate between the use of four elements with which a local advantage was found in both perception and development (Burack et al., 2000; Kimchi et al., 2005), and the use of 12- and 16-element stimuli with which a global advantage was found (Kimchi et al., 2005; Mondloch et al., 2003). Moreover, Scherf et al. (2009) found a more nuanced developmental pattern, in which a local advantage was found for children, adolescents, and adults in the 4-element displays, whereas adults, but not children or adolescents, showed a global advantage with 16-item displays. Kimchi (2012) argued that this discrepancy in findings might be explained by the nature of the task as Scherf et al. used a primed matching task, which might require advanced representation skills that are not available to young children and are only developing in adolescents.

In the selective attention task, the requirement was to report the shape at only one level within a block of trials, while ignoring

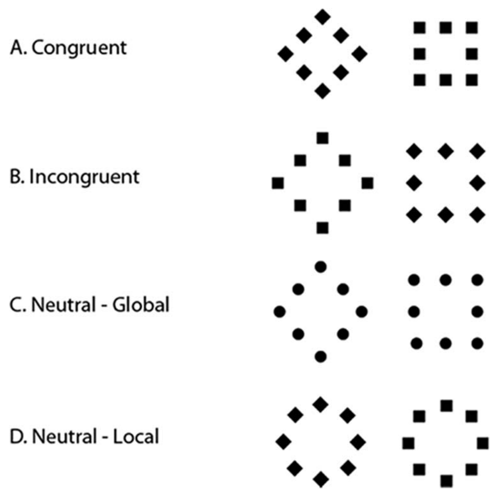

Figure 1. Stimuli for selective and divided attention tasks. Schematic drawing of stimuli (not drawn to scale). (A) Congruent stimuli were made up of the same target shape at both levels of the stimulus. (B) Incongruent stimuli had one target shape at one level of the stimulus and the other target shape at the other level of the stimulus. (C, D) Neutral stimuli were made up of a target shape at one level of processing, either at the global level (C) or the local level (D), and a neutral shape at the other level of processing. All stimuli were used for the selective attention task, and the neutral stimuli were used for the divided attention task.

distracting information at the other level of analysis. In the divided attention task, the target shape could occur at either level, with a neutral stimulus at the opposing level of analysis. The effects of divided and selective attention tasks on the processing of hierarchically integrated stimuli were examined in relation to developmental level among groups of children with average ages of 6, 8, 10, and 12 years, and a group of adults with an average age of 24 years. The focus was on the higher order attentional processes involved in coordinating resources between the parts and whole of the visual pattern.

The responses for both the selective and the divided attention tasks entailed target discrimination between two stimulus shapes (a left key press was associated with a diamond stimulus, and the right key was associated with a square stimulus, or vice versa for counterbalanced trials). The participants were required to respond as rapidly as possible on each trial by pressing on the designated key for the diamond or square targets that could appear at either the global or local level.

The inclusion of selective and divided attention tasks provided the opportunity to examine converging evidence for the influence of both explicit and implicit processes of attention. Explicit manipulations of attention were assessed in the selective attention task, wherein the participants were instructed to attend to a particular level of analysis. Here, performance was measured with three conditions of target compatibility; in the congruent condition, the targets at one level were the same shape as the items at the other level of analysis (e.g., a diamond made up of smaller diamonds). In the incongruent condition, the presented shapes were different at competing levels (e.g., a diamond made up of smaller squares). In the neutral condition, the shape at the competing level was not a potential target (i.e., it was a circle). In contrast, implicit attention was examined in the divided attention condition through the inclusion of a probability manipulation about which the participants were naïve (cf. Lamb, Pond, & Zahir, 2000). The targets appeared at the global level 0%, 20%, 50%, 80%, or 100% of the time within a set of 100 trials (across two blocks), implicitly guiding attentional focus and strategy to the most frequently occurring level of visual analysis (Fremouw, Herbranson, & Shimp, 1998).

The primary question for the present study concerned the development of attention to the structural level of analysis: Are similar trajectories seen on both types of tasks? Second, we sought to uncover whether the processes associated with the implicit guidance of attention in our probability manipulation in the divided attention task showed a similar trajectory to the processes associated with the explicit manipulation of attention as used in the selective attention task.

Method

Participants

The participants included 23 6-year-olds (M = 73 months, SD = 3.5 months), 23 8-year-olds (M = 98 months, SD = 3.5 months), 19 10-year-olds (M = 123 months, SD = 4 months), 19 12-year-olds (M = 144 months, SD = 3.4 months), and 20 adults (M = 293 months, SD = 41 months). The children were recruited from an elementary school in the Montreal, Canada, area, and the adults were undergraduate and graduate students from McGill University. All of the participants completed both the selective attention and divided attention conditions on different days, and the order of presentation of conditions was counterbalanced among participants.

Apparatus and Stimuli

A G3 Macintosh computer, running Vscope software (Enns & Rensink, 1992), with a 15-in. Viewsonic screen (placed approximately 58 cm from the observer) was used to generate the displays and collect the data. The participants responded on each trial by pressing one of two computer keys that were indicated by a sticker placed over them.

All of the items were drawn in black on a white background. Each element was centered in a box of 160 × 160 pixels. All stimuli measured 4 cm (4° of visual angle) both horizontally and vertically. One of the eight target stimuli was presented on every trial and always appeared at central fixation of the computer screen. For each trial, the stimulus remained on the screen for 1 s or until a response was made. If a response was made, one of the two feedback signals was presented—a plus sign ("+") for a correct response, and a minus sign ("–") for an incorrect response. If no response was made within 3 s, a zero was presented to indicate that the trial timed out. Trials in which the observer made no response were counted as errors. The feedback/fixation stimulus, which also served as the fixation for the next trial, was presented for 1 s immediately upon response or at the end of the 3 s time-out period. The next stimulus was presented 500 ms after the offset of the fixation. The same keyboard presses were used for the divided and selective tasks; one key for whether stimulus contained a diamond and another button if the stimulus contained a square (the zed ["z"] and forward slash ["/"]) keys were used, counterbalanced across participants).

Selective Attention Task

The target stimuli were global squares, diamonds, or circles that were made up of eight circles, squares, or diamonds. The task was comprised of 240 trials, with three blocks of 40 trials for both the attend-to-global and attend-to-local conditions (for a total of 120 attend-global and 120 attend-local trials). The participants were instructed to either attend and respond to information at the global level and ignore shapes that appeared at the local level, or to attend and respond to information at the local level while ignoring global level information. The trials varied with regard to the global level shape and the local level shape, specifically with regard to the level consistency of the stimuli.

Targets that were the same shape (either a diamond or a square) at both the global and local level were considered congruent. Targets that were either a diamond at the global level and a square at the local level, or a square at the global level and a diamond at the local level, were considered incongruent. Targets presented with circles at the ignored level (i.e., as either a diamond or a square at the global level and circles at the local level, or a circle at the global level and diamonds or squares at the local level) were considered neutral (see Figure 1C and D).

The session began with either the attend-to-global condition or the attend-to-local condition, and these two conditions were counterbalanced across participants. One block of practice trials was administered before both the global and local conditions. Order and type of stimulus that appeared on any trial within the attend-to-global or the attend-to-local condition blocks were randomly intermixed and equally likely.

Divided Attention Task

The four stimuli in the divided attention task included a global square and a global diamond, each made up of eight circles, and global circles made up of either eight local squares or local diamonds. These stimuli were the same as the neutral stimuli from the selective attention task and are presented in the bottom 2 rows (C and D) of Figure 1.

The administration of the test entailed 10 blocks of 50 trials. Within each pair of two blocks, the probability of presenting the target (randomly a square or a diamond) at one or the other level was manipulated. For example, in the 20% global biasing blocks, each block of 50 trials included 10 global targets and 40 local targets; for the 80% global biasing block, the reverse was true with 10 local targets and 40 global targets. The biasing conditions included 0% global (i.e., 100% local targets), 20% global, 50% global, 80% global, and 100% global, with 100 trials for each condition divided into two blocks. The two blocks of each biasing level were administered sequentially and the five levels were counterbalanced across the participants to control for practice and order effects. Counterbalancing was accomplished by creating a random order of the five levels (e.g., 80%, 20%, 50%, 100%, 0%) that was administered to the first participant. For each following participant, the first condition (e.g., 80%) was moved to the end of the list. After five participants, the order was reversed and the procedure was repeated. After 10 participants, a new random order was generated. A practice block of 50 trials of the unbiased condition (25 global and 25 local targets) was administered prior to the 10 blocks of 50 trials.

Procedure

The participants were tested in two sessions, separated by an interval of 1 week. During the first testing session, the participants were administered either the selective or divided attention task. Half of the participants in each group received the divided attention task first and then the selective attention task, and the other half were administered the tasks in the reverse order. Prior to beginning the task, cards with the possible targets were shown to the observers, and care was taken to ensure that the corresponding key presses were learned.

Results

Selective Attention Task

Reaction time (RT) data. The RT and error data for the selective attention task are presented in Figure 2. These data were analyzed with a mixed-model ANOVA with Age (6, 8, 10, 12, 24) as the between-group variable, and Target Consistency (congruent, neutral, incongruent) and Level (global, local) as the within-group variables. This analysis revealed that older participants were quicker to identify targets than younger participants, $F(4, 99) = 78.22$, $p < .001$, global targets were identified faster than local targets, $F(1, 99) = 63.37$, $p < .001$, and congruent, neutral, and incongruent targets produced different RTs, $F(2, 99) = 69.59$, $p < .001$. A two-way interaction between Age and Level revealed that the difference between global and local targets decreased with age, $F(4, 99) = 4.42$, $p = .003$. The interaction between Age and Consistency indicated larger effects of consistency for younger

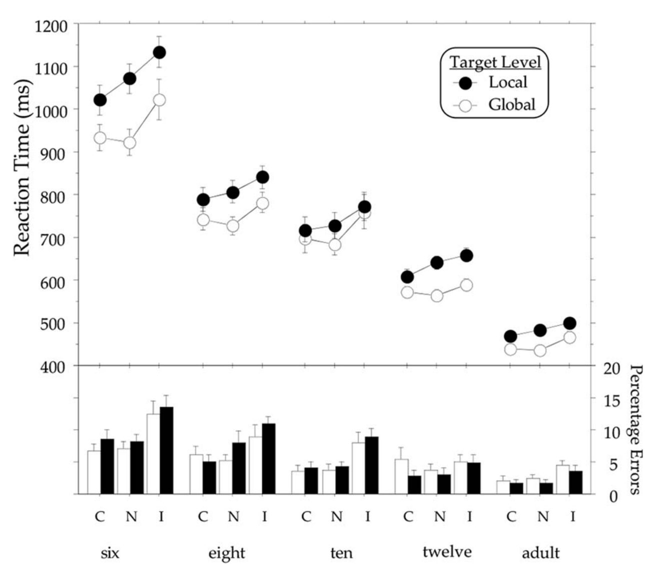

Figure 2. Selective attention task reaction time and error rates. Reaction time and error data plotted for the selective attention task for all age groups. Error bars represent the standard error of the mean, between subjects. C = congruent targets; N = neutral targets; I = incongruent targets.

children, $F(8, 198) = 4.42$, $p < .001$. The effect of Consistency was also different for global and local figures, producing a two-way interaction among Level and Consistency, $F(2, 198) = 7.05$, $p = .001$. The three-way interaction between Age, Consistency, and Level was not significant.

Cost–benefit analysis of selective attention task. To further explore the two-way interaction between Age and Consistency, costs and benefits were computed as the difference between the mean RT for neutral targets and the mean RT for incongruent and congruent targets, respectively; these scores were used in two separate analyses, one for costs and one for benefits. For each, a two-factor mixed design ANOVA was conducted with the repeated measures factor of Level and the between-groups factor of Age (see Figure 3). In terms of benefits (neutral RT – congruent RT; see left panel of Figure 3), there was a main effect of Level, $F(1, 99) = 15.22$, $p < .001$, with local targets being aided by congruent information at the global level, whereas global targets were unaffected by congruent information at the local level. We also repeated this analysis to take potential overall age differences in RT into account and the effect of Level remained significant. The omnibus F did not reveal an effect of age, or a significant interaction between age and level. Thus, we found significant benefits for congruent global forms on local shape discrimination, regardless of age. In contrast, a developmental trajectory was found in which the 6-year-olds showed larger benefits than the older participants for local targets (please see Figure 3).

The advantage for local-level targets was confirmed by post hoc one-sample t tests for each age group, $t(22) = 3.29$, $t(22) = 4.33$, $t(18) = 3.39$, $t(18) = 4.04$, $t(19) = 3.88$, for Ages 6, 8, 10, 12, and 24 years, respectively, all ps $<.005$. None of the similar tests for the global targets were significant, all ts < 1.65, indicating no benefit for global targets by consistent local items.

In terms of costs, (incongruent RT – neutral RT; see right panel of Figure 3), a main effect of Target Level, $F(1, 99) = 5.59$, $p = .02$, was found, with costs being larger for global targets than for local targets. This was surprising given that the benefits were predominantly seen when responding to the local targets, but also because the global precedence hypothesis predicts that the global form will have a greater impact on responses to the local rather than to the global shapes. This finding of interference from local-level information on global-target processing supports our claim that the stimuli we used were more balanced in terms of their configuration than those previously used (cf. Burack et al., 2000; Kimchi et al., 2005; Mondloch et al., 2003). Nonetheless, some degree of global precedence effect is still evident with these stimuli in terms of the relative benefits of global distractors on local processing and the overall faster RTs for global forms.

In terms of age-related effects on costs, we found a general improvement in the ability to ignore information at the target-irrelevant (distracting) level, $F(4, 99) = 4.33$, $p = .003$. This age-related improvement was similar for both levels of analysis, and there was no interaction between Age and Level. Comparing the different ages revealed an improvement between 6 and 8 years of age, $p = .025$. However, a regression was evident for the 10-year-olds, as their performance was not better than that of the 6-year-old group, and worse than those of the 12-year-old and 24-year-old groups. This may be because the age range between 8 and 12 years may represent a marked shift in processing style for hierarchical global–local stimuli within the context of a task that requires the coordination of attention between the two levels.

Error data. The errors were examined with a mixed-model ANOVA with Age (6, 8, 10, 12, 24) as the between-group variable, and Level (global, local) and Target Consistency (congruent, neutral, incongruent) as the within-group variables. This analysis revealed a main effect of Age, $F(4, 99) = 10.47$, $p < .001$, and Consistency, $F(2, 198) = 34.13$, $p < .001$, indicating that a decrease in errors was associated with increasing age, and that the participants committed fewer errors on trials with congruent and neutral targets than on trials with incongruent targets. An Age $\times$ Target Consistency interaction, $F(8, 100) = 2.1$, $p = .04$, revealed that the benefits of the congruent targets increased with age (see bottom panel of Figure 2). No evidence for a speed–accuracy trade-off was found in these data.

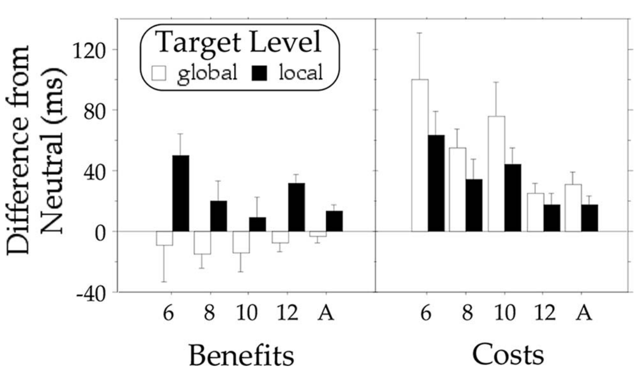

Figure 3. Cost–benefit analysis for selective attention task. Costs and benefits derived from the selective attention task. Benefits were computed by subtracting the mean reaction time for congruent targets from that for neutral targets (neutral – congruent) for each individual participant. Thus, positive numbers indicate faster responding on congruent than neutral trial types. Costs were computed by subtracting the mean reaction time for neutral targets from that for the incongruent targets (incongruent – neutral) for each individual participant. Thus, positive numbers indicate slower performance on the incongruent trial types compared with neutral. Error bars represent the standard error of the mean, between subjects.

Divided Attention Task

RT data. The correct RT data for all of the biasing conditions in the divided attention task were analyzed with a mixed-model ANOVA, with Age (6, 8, 10, 12, 24) as the between-group factor, and Level (global, local) and Biasing Condition (0%, 20%, 50%, 80%, 100% global) as the within-groups factors (see Figure 4). These results indicated slower RTs among the younger participants, $F(4, 99) = 70.76$, $p < .001$, faster responses to global targets than to local targets, $F(1, 99) = 113.08$, $p < .001$, and a decrease in RT in relation to the increase in biasing manipulation, $F(3, 297) = 84.291$, $p < .001$. The main effect of Bias was moderated by an interaction with Age, $F(12, 297) = 2.52$, $p = .004$, as the 6-year-olds were not sensitive to the biasing manipulation. Biasing was more effective overall for global than local targets, $F(3, 297) = 3.48$, $p = .016$.

A three-way interaction among Age, Level, and Bias indicated that the biasing manipulation was effective for older children and adults, and that this trajectory was different for global and local targets, $F(12, 297) = 2.15$, $p = .014$. This three-way interaction

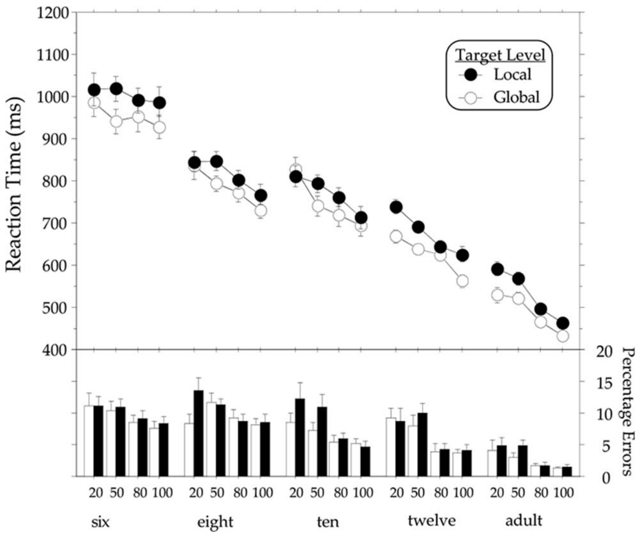

Figure 4. Divided attention task—data. Reaction time and error data plotted for the divided attention task for all age groups. The numbers along the *x*-axis represent the percent bias manipulation (20%, 50%, 80%, and 100%), such that for the blocks of trials contributing to that data point, there were that percentage of local or global targets across the block. Error bars represent the standard error of the mean, between subjects.

was further explored using a summary measure of the bias effect. The Level × Age interaction, which is important for looking at differences in attention to global and local forms across age, approached significance, $F(4, 99) = 2.06$, $p = .093$.

Summary statistic of bias. The slope relating mean correct RT with percent target occurrence (20%, 50%, and 80%) was computed for each individual for global and local targets. These slopes were submitted to a two-factor mixed design ANOVA with the between-groups factor of Age and the within-groups factor of Level (see Figure 5). Values close to zero indicate the lack of an effect, whereas large negative numbers indicate that the target level probability manipulation had an impact on the RT for those blocks of trials. Bias was far more effective for older than for younger observers, $F(4, 99) = 3.57$, $p = .013$. The slope value for 6-year-olds was not significantly different from zero using a one-sample *t* test, $t(22) = -1.64$ for global targets, and $t(22) = -1.48$ for local targets. The same analysis for all other age groups, for both global and local targets, showed a slope significantly less than zero, $p < .025$ in all cases. The main effect of age was modulated by Level, $F(4, 99) = 3.35$, $p = .013$, indicating different developmental trajectories for the two levels of analysis. As is evident in Figure 5 and confirmed by simple effects analysis and subsequent Fisher PLSD comparisons, there was a marginal effect of age for the global targets, $F(4, 99) = 2.36$, $p = .058$, that was attributable to the difference between the 10-year-olds and the 6- and 12-year-olds. As all age groups other than the 6-year-olds showed a significant effect of bias, the developmental shift between 6 and 8 years of age for the global targets suggests that adult level sensitivity to changing target level probability is evident at 8 years of age. However, the transition between 10 and 12 years of age indicated that the excessive sensitivity to the bias manipulation in the 10-year-olds was normalized to adult levels for the 12-year-olds. In contrast, for the local targets, there was a robust developmental trend, $F(4, 99) = 5.11$, $p = .001$, with a shift between 6 and 8 years when some influence of the biasing manipulation begins followed by a marked shift between 10 and 12 years. Thus, for global targets, adult level sensitivity to the biasing manipulation was seen by 8 years of age, whereas for local targets, this level of performance was not evident until 12 years. This appears to represent two distinct developmental stages for the processing of these stimulus probabilities and the associated implicit attention required—one from 6 to 8 years, and a second from 10 to 12 years.

Error data. The percentage of incorrect responses was examined with a mixed-model ANOVA with Age (6, 8, 10, 12, 24) as the between-group factor and Bias (20%, 50%, 80%, 100%) and Target Level (global, local) as the within-group variables. This analysis revealed main effects of Age and Target Level, as younger observers committed more errors than older observers, $F(4, 99) = 10.02$, $p < .001$, and more errors were committed with local targets than with global targets, $F(1, 99) = 7.43$, $p = .008$. A main effect of Bias, $F(3, 100) = 34.98$, $p < .001$, supported the effectiveness of this manipulation. Faster RTs were associated with fewer errors, thereby reducing the likelihood that differences in RT data reflect a trade-off of speed for accuracy (see Figure 4, bottom panel). A summary statistic for the error data was not deemed necessary because no interaction between age and any other factor was found.

Post Hoc Cross-Task Analysis

Given the similar task requirements and stimuli across the divided and selective attention tasks, we conducted an exploratory analysis to compare the impact of the context in which attention was measured. To do so, the RT data derived from the 100% global- and 100% local-target conditions in the divided attention task, and the RT data from the neutral targets in the selective attention task (same target conditions, but different task instructions), were compared to examine the effects of performing a

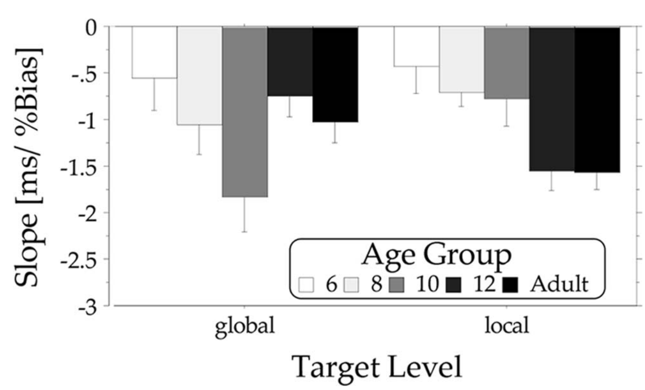

Figure 5. Summary measure of bias effect for divided attention task. Summary measure of bias effect for reaction time data from the divided attention task. The *y*-axis presents the slope of the best-fitting straight line relating percent target present (biasing manipulation; 20%, 50%, and 80%). Values close to zero represent insensitivity to this biasing manipulation. Along the *x*-axis are the two target levels and the different age groups are represented by darker shades of gray. Error bars represent the standard error of the mean, between subjects.

divided versus a selective attention task. This exploratory analysis concerned the different trajectories for attention to one level or the other. A relative processing difference would be revealed by an Age × Level interaction without any contribution of the task (selective or divided attention). If the predominant change was associated with attentional maturation, then Task should enter into the interaction with Age. If both level and task are important, then development may be associated with the deployment of attention to one specific level (local or global).

RT data. RTs were faster among the older compared with the younger participants, $F(4, 100) = 100.55$, $p < .001$, and RTs were faster with global compared with local targets across all ages, $F(4, 100) = 109.84$, $p < .0001$. An Age × Level interaction, $F(4, 100) = 5.41$, $p < .001$, revealed that this difference decreased with age. A marginally significant three-way interaction among Age, Task, and Level, $F(4, 100) = 2.25$, $p = .067$, was further examined using simple effects ANOVAs, on the grounds that this was the a priori prediction of a task difference. Simple effects analyses revealed an interaction of Level × Task for the 6-year-old, $F(1, 22) = 15.06$ $p < .005$, and the 8-year-old, $F(1, 22) = 5.01$ $p < .05$, groups, but not at the older ages ($p > .05$; see Figure 6). Thus, one of the main developmental changes was the ability to selectively attend to the local level of analysis. No differences were found across the tasks for the global-level stimuli, but a large increase in RT for selectively attending to the local level of analysis was evident. Apparently, selectively attending to the local level, but not the global level, appears to hurt the performance of the 6-year-old and 8-year-old children, but not that of older children and adults. This claim is consistent with the findings from the biasing manipulation (see Figure 5), for which adult proficiency was not seen until 12 years of age, with pronounced deficits at 6 years of age. It is also consistent with the larger benefits seen for the local stimuli from congruent global form in the selective attention task (see Figure 3).

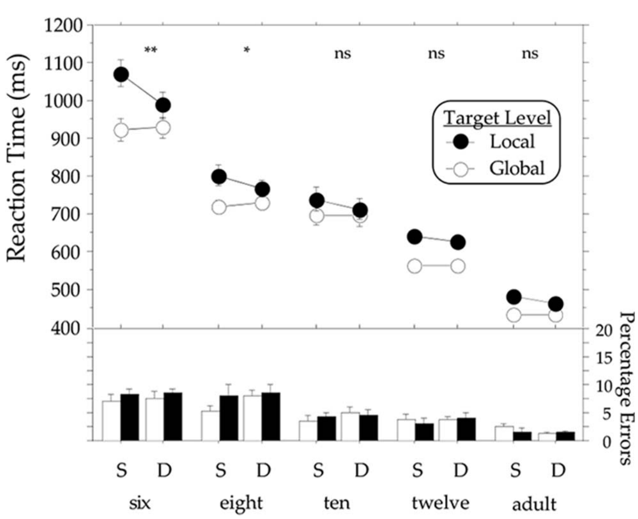

Figure 6. Comparison of performance in the selective and divided attention tasks. For the selective attention task (S), the mean reaction time and error rates in the neutral conditions were used. For the divided attention task, the mean reaction time and error rates from the 100% bias condition was used. The stimuli and responses were the same in both tasks; as such, differences in performance between the tasks were attributed to a difference in mind-set—selective for one level of analysis compared with divided across both levels. Error bars represent the standard error of the mean, between subjects.

Error data. An analysis of error data revealed an effect of Age, $F(4, 100) = 12.72$, $p < .001$. Neither main effects, nor interactions, nor speed–accuracy trade-offs were found (see Figure 6, bottom panel).

Discussion

The primary question for the present study concerned the developmental trajectory of selective and divided attention in relation to hierarchical level. We found converging evidence for separate developmental trajectories for global and local stimuli, and distinct patterns of performance for observers of different age groups. At the most general level, the ability to process the global level of analysis appeared to develop sooner than attention to local forms. This was evidenced in the divided attention task, which included the implicit attention-directing bias to either the global or local levels of analysis. Here, the implicit bias to the global level was adult-like by 8 years of age and improved at 10 years, whereas the implicit bias toward local processing gradually improved between 6 and 10 years of age and was not adult-like until 12 years of age (compare the right and left panels of Figure 5).

Consistent with these trajectories in the sensitivity to an implicit biasing manipulation, selective attending to the local level entailed costs for the 6- and 8-year-old children, who displayed slower RTs to the local targets when explicitly directed to attend to the local level than if they had divided their attention between the two levels. By 10 years of age, this cost was reduced and no longer significantly different from processing in the divided attention condition (see Figure 2). We interpret this cost as evidence of a difficulty in the explicit directing of attention rather than in local processing, as the comparison involved identical stimulus presentation and response demands across the two tasks. That is, the only difference between the specific trials in this comparison was the way attention was deployed (divided vs. selective). Thus, the ability to attend to global form developed prior to, and may even have been necessary for, expertise and control over attention to the local form.

The overall pattern of findings provides some evidence from selective and divided attention tasks that 10 years of age may represent a transitional age in processing style. Four data points converge to support this claim. One, in the divided attention task, bias to global form appeared to increase dramatically at this age, and then was normalized to more adult-like levels (see Figure 5, left panel). Two, the ability to bias processing to local level only reached adult-like levels after this age (see Figure 5, right panel). Three, the costs associated with an incongruent distractor increased significantly at this age despite near adult-like levels at 8 years of age. Four, the tentative results in the exploratory cross-task analysis, specifically, the significant cost of attending to local targets that was associated with the 6- and 8-year-olds, was no longer evident at this age. Although these four data patterns from different tasks are convergent evidence for a transition at 10 years of age from a generally inefficient global processing bias to a more controlled local-level analysis, coincident with greater efficiency at attending to the global level, future research should confirm this trend, as we did not originally set out to test this hypothesis.

Implications

Kimchi et al. (2005) argued that the processing of many small items or few large items was associated with different levels of processing (see also Goldmeier, 1972; Klein & Barresi, 1985) and development. We attempted to design stimuli that tapped an intermediate level in terms of numbers of local component parts of larger global wholes, to explore the role of attention in the processing of visual form. The data from the selective attention task support our choice of stimulus parameters. In particular, when attending to one level (either global or local), the information at the other level interfered with processing. However, the extent of the interference was not symmetric, as the interference from the local level on global processing was greater than in the reverse direction. Moreover, benefits of global form on local processing were found, whereas the reverse effect was not found. Based on these findings, we suggest that these stimuli permitted the examination of how attention, and the development of attention, can bias the relative processing of hierarchal form level independent of absolute level processing elicited by stimulus parameters. That is, we attempted to create stimuli that were equally biased to the global and local levels, and then manipulate attention between levels; we appear to have been mostly successful in this attempt.

The attentional trajectory that we observed, with 6- to 8-year-olds looking less mature on attention to local than global form, parallels findings in a previous study with the same type of stimuli (Porporino, Shore, Iarocci, & Burack, 2004). In that study, the participants were asked to categorize a central figure while ignoring two flanking stimuli that may or may not have included distracting information. The control stimuli either included a pair of neutral flanking stimuli or no flanking stimuli. The effect of the flanking stimuli was only seen in the processing of the global targets, with a clear benefit in the conditions without the flanking stimuli. Conversely, the RTs for the local targets were similar with or without the flanking elements, as if processing at the local level was already maximally difficult (cf. Lavie, 1995). The convergence from these very different tasks bolsters the claim that explicit attention to local elements for young children (6 to 8 years) represents a particular challenge.

The difference in the findings between the tasks seen there is consistent with Plaisted et al.'s (1999) contention that divided, compared with selective, attention tasks are more sensitive to group differences. They did not find any differences between a typically developing group and a group of young people with autism on a selective attention task, but did find a clear bias toward the local elements among the children with autism in a divided attention task. Thus, task instructions moderated performance such that explicit information regarding the level to which the participants should attend in the selective attention condition facilitated performance in both groups. However, when the participants were required to attend to both levels of analysis in the divided attention condition, the participants with autism consistently biased their attention toward the local level. In the present study, we found more robust developmental trajectories with the divided, rather than the selective, attention task, although both revealed similar patterns across age. Thus, the divided attention task may provide a more sensitive measure of subtle differences across age and special populations.

The use of a probability manipulation to bias attention in the divided attention task entails a potential interpretation problem when considering whether the developmental change comes from implicit or explicit perception of the relevant probabilities, or from the ability to implement that knowledge in the attentional system. In the current task, we attempted to control for bias in conscious awareness by randomly presenting the respective blocks of trials. Nonetheless, we did not explicitly ask participants whether they were aware that targets on some trials appeared more frequently at the global or local level. However, even adult viewers have been found to experience difficulty making use of implicit learning to improve performance, and are not readily able to estimate probabilities (Vaquero, Fiacconi, & Milliken, 2010). Moreover, if viewers were consciously aware that some blocks of trials were biased to one level of analysis, we would expect a similar trajectory for global and local form perception, and this was not the case in our data.

Based on evidence from a similar task with identical stimuli, Iarocci, Burack, Shore, Mottron, and Enns (2006) support the claim that the critical ability is in the *implementation* and not *perception* of the probabilities. The participants were required to search for a unique item in a display of one, two, or nine items, and then identify whether it was a diamond or a square. Iarocci et al. observed similar bias effects for the global targets as observed here, with faster responding to the global targets when they were presented more often in a block (70% in that experiment) and slower responding with fewer presentations of global targets (30% global). For the local targets, the observers were slower at identifying the shape at the local level when biased to global form, again as observed here. However, when biased to the local level, the typically developing children of all ages (between 6 to 12 years of age) were actually *slower* to respond to local targets than when there was no bias (i.e., 50% of targets were global in the block). Thus, the participants could detect the difference in probability (more frequent presentation of local targets), but when they attempted to bias attention to the local level, their performance was worse on this visual search task (see Iarocci at al., 2006, Figure 4). Based on those data, Iarocci et al. concluded that young observers (aged 6 years) could detect the probability manipulation but not adequately implement the processing necessary to utilize this information. The present experiments do not allow a similar analysis, but do not refute the previous claims that 6-year-olds cannot implicitly implement an appropriate level bias; this claim is consistent with our current data.

Conclusions

Although we observed two developmental shifts in our data—one between 6- and 8-year-olds and a second between 8- and 10-year-olds, we suggest that the first shift represents a quantitative improvement in performance, whereas the second shift reflects a qualitative change in processing style. Specifically, attention to global form appears to develop gradually until 8 years of age, and then, once adult-like or better-than-adult-like performance is reached, a rapid improvement in local processing is observed. This pattern of development is reminiscent of early claims concerning the ontogenesis of form perception (Werner, 1935; see also Enns, Burack, Iarocci, & Randolph, 2000). From this perspective, children were assumed to be global processors early in life, followed by increasing expertise at this gist or scene-level analysis. Perception at the local level progressed to adult-like performance only with expertise at the global level. Although we do not make claims about perception at one or the other absolute level (i.e., a level precedence effect; cf. Navon, 1977), we suggest that the attention system of the developing brain may be biased to process global form early in life and that selection at the local level is relatively difficult at these young ages (6 to 8 years of age).

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