International Journal of Behavioral Development
2004, 28 (4), 358–364
http://www.tandf.co.uk/journals/pp/01650254.html

DOI: 10.1080/01650250444000063

A developmental change in selective attention and global form perception

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The primary purpose of the present study was to examine the processing of local and global perception in relation to selective attention during development from childhood to early adulthood. Filtering was the specific component of selective attention that was examined. The influence of varying distractor congruency and compatibility on relative local-global processing was also examined. Distractor congruency and compatibility did not differentially affect local and global processing. With the presence of neutral distractors, however, 6- and 8-year-old participants demonstrated a greater increase in RTs for global targets relative to local targets whereas older children and adults showed the same pattern of RTs for both local and global targets. The results are suggestive of separate developmental trajectories for global and local level processes, with global processing undergoing developmental change at least until 8 years of age.

Introduction

Most visual patterns can be organised perceptually into hierarchical levels of form. For example, when an observer attends to a house, visual attention can be directed to the individual features of the house (e.g., bricks, door, or windows), to the entire house, or to both. When an image is visually parsed into separate units, the analysis is referred to as local perception, and when the overall structure of the image is processed, the analysis is referred to as global perception (Enns & Kingstone, 1995; Navon, 1977). The abilities to process both local and global information develop in early childhood, although the trajectories of each are independent from the other (Burack, Enns, Iarocci, & Randolph, 2000; Enns, Burack, Iarocci, & Randolph, 2000). These separate trajectories reflect underlying differences in development between specific aspects of attention that might, in turn, affect and be affected by still other aspects of attention. For example, the necessity to filter nontarget stimuli in the environment in order to attend to the target information might entail competition for attentional resources and, thereby, diminish the efficiency of global or local processing or both. The nature and magnitude of this effect is largely contingent on stage of development as the independent developmental trajectories for local and global processing as well as filtering may be associated with differing levels of efficiency and utilisation of resources. In this study, we examined the relation among these developmental trajectories by assessing age-related changes in local and global perception when filtering abilities are required.

Developmental change in global and local processing

Issues concerning the development of local and global perception were typically centred on the question of the priority of hierarchical level. One early view was that children are primarily holistic, or global, processors as evidenced by infants' initial focus on the external contours of line drawings and later inclusion of interior details (Fantz, 1961; Ghim & Eimas, 1988; Quinn & Eimas, 1986). This notion of global precedence was further supported by evidence that young children tend to categorise objects on the basis of their overall similarity rather than on the similarity of the components (Ames, Metraux, Rodell, & Walker, 1974; Smith & Kemler, 1977).

The utility of this line of research was questioned, however, as the developmental sequence of local to global processing is more complex than originally suggested (Burack et al., 2000). Young children can attend to both global and local attributes under appropriate conditions (Stiles, Delis, & Tada, 1991), but may show impairments under certain conditions. For

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This paper is based on a thesis submitted by Mafalda Porporino as partial fulfilment for an MA degree in the Department of Educational and Counselling Psychology at McGill University. We thank all the students who participated in this study, and their teachers and principals. We thank Hanna Kovshoff, Tara Flanagan, Catherine Zygmuntowicz, and Eva Dolenszky for their help with data collection. The work by Mafalda Porporino and Jake Burack was supported by a research grant from the Social Sciences and Humanities Research Council of Canada to Jake Burack. David Shore thanks the Killam Trust funds (Dalhousie) and the Rotman Research Institute for post-doctoral fellowships for their funding of this project.

example, Prather and Bacon (1986) found that children between the ages of 2 years 7 months and 5 years 7 months are able to name both part and whole aspects of simple pictures, but are less likely to name both aspects of the more difficult pictures, indicating that the capacity to perceive multiple aspects of a display may be secondary to the effects of stimulus or task complexity. Yet, even the effect of stimulus or task complexity can be related to developmental differences in trajectories between global and local processing, as children's global processing appears to be more vulnerable to changes in task difficulty and stimulus structure (Dukette and Stiles, 2001). This evidence is consistent with the notion that global and local perception involve separate mechanisms (Enns & Kingstone, 1995; Rensink & Enns, 1995; Trick & Enns, 1997), as reflected in the developmental findings that the adult-like efficiency is attained earlier for local than for global processing (e.g., Burack et al., 2000; Dukette & Stiles, 1996). Thus, charting the development of global and local processing involves the consideration of task complexity as well as the separate trajectories for each.

Changes in filtering across development

The term filtering is used to refer to the related notions that only a subset of possible perceptual attributes are permitted through a processing "gate" (e.g., Broadbent, 1958; Plude, Enns, & Brodeur, 1994) and that the inhibition of task-irrelevant information is essential to task performance (Enns & Akhtar, 1989; Erikson & Erikson, 1974). Everyday examples of filtering include focusing on the principal dancer as opposed to the other dancers in a troupe, or focusing on the flight of a pitched baseball against the backdrop of the fans in the bleachers. Accordingly, filtering is typically studied with regard to the ability to maintain optimal performance despite the presence of distracting information in the environment. This ability appears to develop with age until at least some point in early childhood (Akhtar & Enns, 1989; Pastò & Burack, 1997), although the specific developmental trajectory is likely to be affected by the nature and difficulty of the task. For example, Pastò and Burack found that 4-year-old children, as compared to older children and adults, demonstrated slowed RTs with the presence of both close (0.95° of visual angle) and far (5.7° of visual angle) distractors, that the 5-, 7-, and 9-year-olds displayed slower RTs only with the close distractors, and that the adults were not affected by the presence of either set of distractors. In addition, the 4-year-olds were the only group to benefit from the window cue that highlighted the target. Thus, age-related changes in the ability to filter irrelevant information appear to be related to the ability to vary the size of the attentional focus and, therefore, to an interaction between age and task difficulty associated with distractor proximity (Pastò & Burack, 1997).

Filtering efficiency is also related to the content of the distracting information (e.g., Enns & Akhtar, 1989) and to variations in the response set of the target in relation to the distractors. For example, distractors from a different response set from that of the target produces the most interference (e.g., Erikson & Erikson, 1974; Ridderinkhof & Van der Molen, 1995). However, this effect decreases with development in childhood (e.g., Enns & Cameron, 1987; Enns & Girgus, 1985), thereby providing further evidence of the complex relation among development, task requirements, and performance.

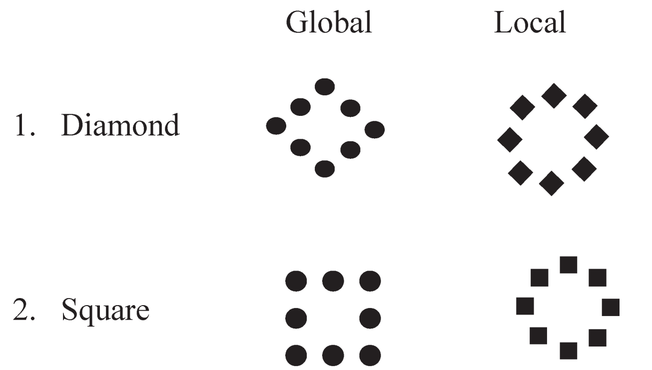

Figure 1. Stimuli used in the filtering task. Global and local refer to the hierarchical level to which the observer must respond. For each, the appropriate response could be "diamond" or "square" as indicated on the left column.

Scope of the present study

In the present study, local and global visual processing in relation to filtering demands was examined among groups of children and young adults. Target stimuli included squares and diamonds at both the global and local levels of structure. The local level stimuli were circles made up of squares or diamonds, and the global level stimuli were squares or diamonds made up of circles (see Figure 1).

Two types of baseline trials were included. In one, no distractors were presented (i.e., the target was presented alone), and in the other, two neutral distractors (i.e., circles made up of circles) were presented on either side of the target (see Figure 2). Differences in performance between these two trial types provide an index of the costs associated with the mere presence of distractors. The presentation of distractors in the display increased task complexity by taxing attentional resources. Filtering was further examined on trials with distractors that varied with regard to the attributes of congruency and compatibility. Congruent distractors shared the same hierarchical level with the target stimulus, whereas incongruent distractors did not (Briand, 1993; Paquet & Merikle, 1988). Compatible distractors shared the same response with the target in a forced-choice situation, whereas incompatible distractors required the other response (see Figure 3). All these trials were intermixed within the same experiment. Since participants were asked to press one button when they saw a big or small square and another button when they saw a big or small diamond; a square target and square distractors shared the same response choice, whereas a square target and diamond distractors involved incompatible response options. On any trial, the distractors were absent, neutral, congruent-compatible, congruent-incompatible, incongruent-

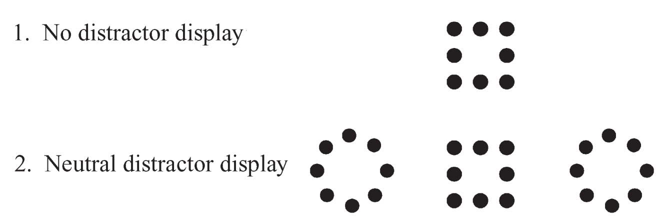

Figure 2. Examples of neutral distractor displays in which there were either no distractors (1) or distractors that contained no response relevant information (2).

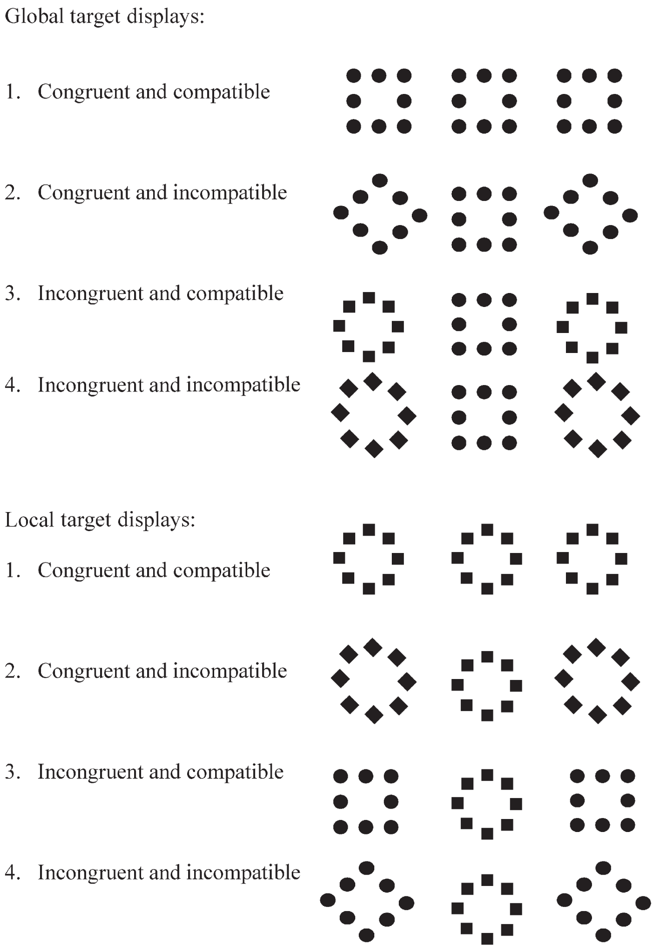

Figure 3. Examples of varied distractor displays. Flanking distractors can be congruent (1, 2; relevant information at the same hierarchical level) or incongruent (3, 4; relevant information at the alternative level) and compatible (1, 3; same response indicated) or incompatible (2, 4; opposite response indicated). This is true for both global and local targets.

compatible, or incongruent-incompatible. These trial displays are presented in Figures 2 and 3.

The primary focus was the differences in developmental changes between global and local perception. On trials with no distractors, we expected to replicate the common finding that global attributes of a display are perceived before local attributes (e.g., Navon, 1983). However, consistent with Dukette and Stiles' (2001) findings, we predicted a greater increase in RTs for global than for local targets when the complexity of the task increased (i.e., neutral distractors were presented), and that the strength of this interaction would decrease with age. The lack of congruence and compatibility between target and distractor was expected to interfere with the performance of all the groups, but especially that of the youngest children, and was expected to impact global processing more so than local processing.

Method

Participants

Twenty kindergarten students (11 females) between the ages of 6.3 and 7.1 years (mean = 6.7, *SD* = 2.5), 20 second-grade students (8 females) between the ages of 7.8 and 8.5 years (mean = 8.2, *SD* = 2.7), 20 fourth-grade students (11 females) between the ages of 9.6 and 10.5 (mean = 10.1, *SD* = 2.6), 20 sixth-grade students (10 females) between the ages of 11.6 and 12.4 years (mean = 12.2, *SD* = 2.8), and 20 university students (11 females) between the ages of 20 and 29 years (mean = 23.8, *SD* = 3.2) participated in the study. The children were recruited from three public elementary schools in the Montreal area and the university students were recruited from McGill University.

Apparatus, stimuli, and design

A G3 Macintosh computer, running VScope software (Rensink & Enns, 1995), with a 15-inch Viewsonic screen, was used to generate the stimulus displays and collect the data. All items were drawn in black on a medium gray background. Viewing distance was approximately 50 cm. Stimuli measured 1.15° of visual angle both horizontally and vertically. One of the four target stimuli was presented on every trial and always in the centre of the computer screen. All distractors were presented at approximately 1.43° of visual angle from the centre of the screen.

The targets were global squares or diamonds made up of eight dots and global circles made up of eight local squares or diamonds (see Figure 1). The task included 200 trials divided into four segments of 50 trials each. Trials varied with respect to distractor condition—no distractors, neutral distractors, or distractors that differed in congruency and/or compatibility to the target. The various distractor conditions appeared equally often across the 200 test trials.

Congruency. On congruent displays, both the distractors and target were from the same hierarchic level. For example, if the target was global in level, and the distractors were also global, then the display was congruent. The congruent targets and distractors could be of the same or different shape. For example, if the target was a global square, the congruent distractors would be a global square or a global diamond. On incongruent displays, the distractors and target were from a different hierarchic level (see Figure 3).

Compatibility. On compatible displays, the distractors and target mapped onto the same response (i.e., square or diamond). Incompatible distractors mapped onto the response other than the target one (see Figure 2)

Procedure

The participants were tested individually in a quiet room. The experimenter displayed a drawing of the targets (square and diamond) at both the global and local level and asked the participants to point to the ''big'' square and diamond and the ''small'' square and diamond. Once the participants responded correctly, they were instructed to focus on the middle of the screen and press a response button (right or left) as soon as a big (global) or small (local) diamond was detected. They were instructed to press the other response button as soon as a ''big'' or ''small'' square was detected. The participants were told to ignore the distractor items that appeared alongside the target item, to maintain fixation at the centre of the screen, and to respond as quickly as they could without making errors.

Each trial began with a fixation symbol that appeared on the screen for 500 ms followed by the display, which remained visible until the participants responded by pressing a response button, or until 2 seconds elapsed. The button press was followed by visual feedback in the form of a plus sign for a correct response, a minus sign for an incorrect response, or a zero if no response was made within the 2 seconds. Trials were treated as errors if the incorrect shape was chosen or if no response was elicited within the designated time. Each segment of 50 trials was followed by a brief pause.

Results

Reaction times from trials with correct responses were subjected to an outlier rejection algorithm (Jolicurer & Van Seltz, 1994) that rejected 405 observations (2.1%) across all subjects and all conditions. These data were excluded from the subsequent analyses. The proportion of errors and the remaining RTs were each assessed with two separate within-observer ANOVAs. The first analysis was focused on the neutral trial types and compared the condition without distractors to that with neutral distractors. The second analysis was focused on the conditions with distractors that varied in congruency and compatibility. All significant effects remained significant when the degrees of freedom were adjusted with the Greenhouse-Geisser (Greenhouse & Geisser, 1959) procedure. Additionally, the factor of block was included in the analysis. Accordingly, the four experimental segments were combined into two blocks of two segments each.

Neutral distractor displays

Reaction time data. The RT data for the neutral distractor displays were analysed with a mixed between-within ANOVA, with age (6, 8, 10, 12, 20 years) and gender (male, female) as between-group variables and level (global, local) and distractor presence (no distractor, neutral distractor) as within-group variables. Older observers were faster than younger observers, $F(4, 90) = 35.28$, $p < .0001$, global targets were identified faster than local targets, $F(1, 90) = 41.15$, $p < .0001$, and the presence of distractors slowed responding, $F(1, 90) = 19.03$, $p < .0001$.

These main effects were moderated by two higher order interactions. The presence of distractors was more evident for global targets than for local targets, $F(1, 90) = 8.38$, $p < .005$ for the Level $\times$ Distractor Presence interaction, and $F(4, 90) = 2.99$, $p < .05$ for an Age $\times$ Level $\times$ Distractor Presence interaction (see Figure 4). This three-way interaction was further assessed with a simple effects analysis (Keppel, 1982), wherein the MSerror and *df* from the omnibus *F* test (reported above) was used in combination with the MSeffect from a separate ANOVA for each age group with the factors of gender, level, and distractor presence. According to this analysis, the two-way interaction between level and distractor presence was significant for the two youngest age groups, $F(1, 90) = 4.01$, $p < .05$ for the 6-year-olds and $F(1, 90) = 14.17$, $p < .01$ for the 8-year-olds, but not for the three older groups, $F(1, 90) < 1.0$, $F(1, 90) = 1.55$, $F(1, 90) < 1.0$ for the 10-, 12-, and 20-year-olds respectively. This interaction for the two younger groups indicated an advantage for a global target presented without distractors.

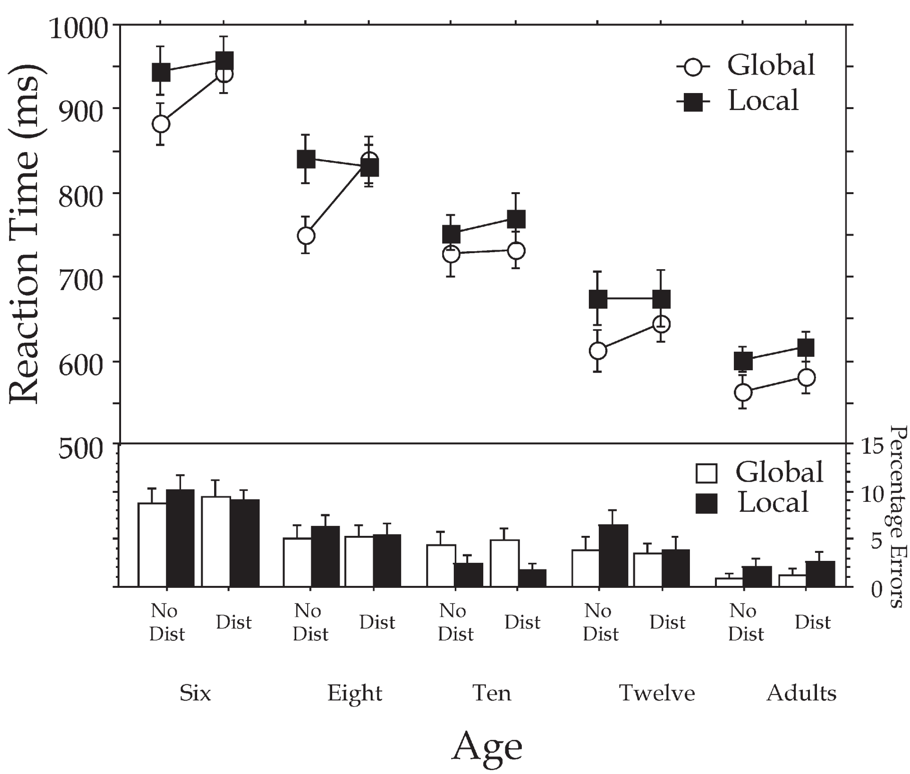

Figure 4. Reaction time and percentage errors for neutral distractor conditions plotted across age for global and local targets. The two-way interaction of target level by distractor presence is significant for the 6- and 8-year-olds and not for the older children and adults. Error bars represent the standard error of the mean between subjects.

Error data. The proportion of incorrect responses was examined with a similar ANOVA. A main effect of age, $F(4, 90) = 14.93$, $p < .001$, indicated that the younger observers made significantly more errors than the old observers. No other main effects or interactions reached significance. Additionally, the pattern of errors closely mirrored that of RT, reducing the likelihood that differences in the RT data reflect a speed–accuracy trade-off.

Varied distractor displays

Reaction time data. The RT data of the varied distractor displays were analysed by repeated measures ANOVA with age (6, 8, 10, 12, 20 years) and gender (male, female) as between-group variables, and level (global, local), congruency (congruent, incongruent), and distractor compatibility (compatible, incompatible) as within-group variables. The common finding of faster RTs with increasing age was evident, $F(4, 90) = 33.58$, $p < .0001$. Additionally, RTs were overall faster with global than with local targets, $F(1, 90) = 28.87$, $p < .0001$. This main effect was moderated by a two-way interaction between level and congruency, $F(1, 90) = 6.06$, $p < .025$, indicating that the global advantage was larger for the congruent conditions than the incongruent conditions (see Figure 5). Although these factors did not interact with age, no significant effect of level was found for 6-year-olds, $F(1, 19) = 4.6$, $p = .05$, and 8-year-olds, $F(1, 19) < 1.0$, $p = .70$, but there was a highly robust effect of level for 10-year-olds, $F(1, 19) = 9.70$, $p = .0057$, and 12-year-olds, $F(1, 19) = 7.64$, $p = .01$, and adults, $F(1, 19) = 16.62$, $p = .0006$. In order for these comparisons to be significant, a level of .01 needed to be reached after Bonferroni corrections for six comparisons. Thus, young children failed to show a global precedence effect in the presence of distractors, whereas a robust precedence was evident in conditions without distractors.

Two higher-order interactions among gender, congruency, and compatibility, $F(1, 90) = 4.90$, $p < .05$ and among gender, level, congruency, and compatibility, $F(1, 90) = 7.97$, $p < .01$ were found. Since these interactions did not involve the factor of age, they will not be discussed further.

Error data. The errors were once again examined with a repeated measures ANOVA with age (6, 8, 10, 12, 20 years) and gender (male, female) as between-group variables, and level (global, local), congruency (congruent, incongruent), and distractor compatibility (compatible, incompatible) as within-group variables. Main effects of age, $F(4, 90) = 16.83$, $p < .0001$, and level, $F(1, 90) = 4.50$, $p < .05$, were found, reflecting faster performance for younger rather than older children and for global rather than local targets.

Discussion

The purpose of the present study was to examine age-related changes in processing global and local information among children and young adults in relation to the influence of filtering and distractor attributes. With the presence of neutral distractors, the 6- and 8-year-old participants displayed the largest increases in RT for global as compared to local targets, whereas the older children and adults showed the same pattern of RTs for targets at both levels of processing. Developmental differences were not apparent in relation to the manipulations between hierarchical level for target and distractor and response set. However, participants of all ages displayed a larger global level advantage when the hierarchical levels of the target and distractors were the same.

In order to determine the costs associated with the mere presence of distractors, two types of baseline trials were included. No distractors were presented in one type of trials, and two neutral distractors were presented on either side of the target in the other. On target-only trials, a global precedence

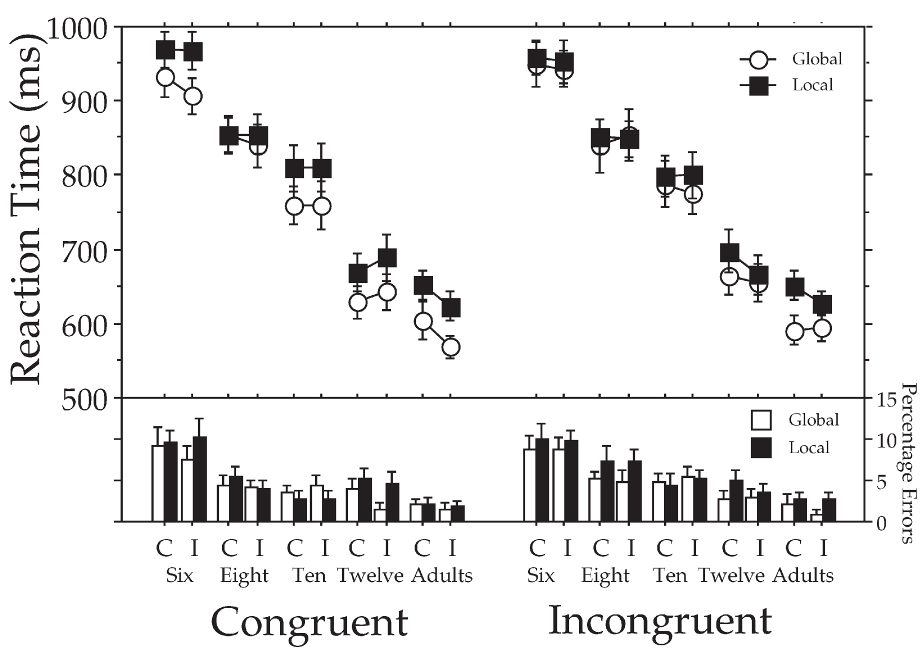

Figure 5. Reaction time and percentage errors for varied distractor conditions plotted across age for global and local targets. The significant interaction between level and congruency is evident in comparing the right and left half of the graph. The main effect of level is only significant for the older children (10 and 12 years) and the adults. Error bars represent the standard error of the mean between subjects.

effect was evident as participants across age groups demonstrated faster RTs when processing global stimuli relative to local stimuli. This finding is consistent with the common finding that global attributes of a display are perceived before local attributes (Kemler Nelson, 1984, 1988, 1989; Navon, 1983), but is also likely to be a function of the specific stimuli used here, as the precedence of global or local stimuli is largely dependent on the characteristics of the stimuli (Enns & Kingstone, 1995; Kinchla & Wolfe, 1979; Robertson, 1996).

The influence of filtering on local and global processing was examined on displays in which a target was paired with neutral distractors. The addition of distractors increased task complexity by introducing a possible source of interference. Six- and 8-year-old children were most affected by the presence of distractors when the target was at the global level, indicating that, relative to local perception, global perception may be more vulnerable to increases in task demands and that adult-like efficiency is attained later than for local perception. We focus here on the relative effect of adding distractors to either global or local targets rather than on the difference between performance for global and local targets.

The development of attention

The finding that distractors interfered with global processing among young children is consistent with Dukette and Stiles' (1996, 2001) findings that children's global perceptual processes are not as elaborate as those of adults and are, therefore, more vulnerable to changes in task demands or stimulus structure. In this study, the global processing of the youngest participants was affected most by the increase in task demands. In the easier, no distractor condition, the global perceptual processes of even the youngest children appeared adult-like. However, with the addition of distractors, 6- and 8-year-olds displayed significant increases in RTs for global targets but not for local targets, suggesting a dissociation between the development of global and local level processes. Consistent with Burack et al.'s (2000) findings, the efficiency of local processing appears to attain adult-like levels earlier on, but global processing continues to improve at least until 8 years of age.

The finding that the younger children in this study were most affected by distractors when the target was at the global level is also consistent with Burack et al.'s (2000) findings, as the RTs for global targets increased with age while RTs for local targets remained fairly constant across age. In the Burack et al. study, however, global perceptual processes continued to improve even after 8 years of age, while the 8- and 10-year-olds performed similarly in the current study. The difference with respect to the 10-year-olds functioning in the current study as compared to Burack et al.'s study is likely to be related to the types of tasks used (visual search vs. filtering), the aspects of attention measured by the task, and overall task complexity.

An alternative explanation for the finding that younger participants were most affected by the presence of distractors when the target was at the global level involves the spatial range of attentional focus. When attending to a local target, the spatial range of attentional focus is considerably more narrow than when attending to a global target. Thus, with a local-level target, attention is focused on the individual items and the overall extent of the visual display does not influence performance, whereas the possibility of capturing attention by external distractors is increased when attention entails a wider focus to encompass the global form. This conclusion is supported by Pastò and Burack's (1997) findings that adjusting the spatial range of attentional focus varies with age, as adult observers showed greater efficiency in narrowing their attentional lens than 4-, 5-, 7-, and 9-year-old children. According to this explanation, the critical developmental change is control over the efficiency with which attention can be focused.

Another way to consider this aspect of attentional control relates to the task presented to the participants. We designed the experiment with three items on the screen; however, in order to perceive these as separate entities they must first be parsed apart from the overall display. This parsing process would necessarily proceed prior to any filtering of the items. The difficulty experienced by the younger children may stem from this parsing processing rather than from a difficulty in filtering already-parsed objects. The present data do not allow us to differentiate between these accounts. While we favour a filtering account based on previous research (i.e., Pastò & Burack, 1997), the lack of a developmental difference in our varied distractor conditions may support the parsing account. In future research, these two factors need to be manipulated in an orthogonal design in order to disentangle the relative contribution of parsing versus filtering parsed objects.

Distractor congruency and compatibility

A final aspect of this study involved the extent to which stimulus attributes of the distractors influenced local and global processing. Distractor compatibility did not differentially affect global or local processing. Distractor congruency, on the other hand, influenced global processing such that the overall global advantage was larger for congruent trials than for the incongruent trials. Although the importance of distractor attributes on relative global and local processing was exemplified by the reported distractor congruency effect, it did not differentiate between age.

Conclusion

Increases in RT for global targets when neutral distractors were present as compared to when a target was presented in isolation indicates that local perceptual processes are not fully established in the early school age period. The lack of interference from distractors on global processing among 10-year-olds, 12-year-olds, and adults suggests that the processes involved in global perception undergo a meaningful change between 8 and 10 years of age. In contrast, the finding that the local processing of young children and adults were not affected by the presence of distractors suggests that this level of processing may reach adult levels of efficiency relatively early in development.

Manuscript received May 2002
Revised manuscript received February 2004

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