Age-Related Change in Shifting Attention Between Global and Local Levels of Hierarchical Stimuli

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Age-Related Change in Shifting Attention Between Global and Local Levels of Hierarchical Stimuli

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The focus of this study was the developmental pattern of the ability to shift attention between global and local levels of hierarchical stimuli. Children aged 7 years and 11 years and 21-year-old adults were administered a task (two experiments) that allowed for the examination of 1) the direction of attention to global or local stimulus levels; 2) the susceptibility to interference of the global or local stimulus levels; and 3) the flexibility in directing attention to global or local stimulus levels. The results revealed a global advantage effect that decreased with age when the task required level shifting from trial to trial. The abilities to resist interference and to flexibly shift attention also improved during childhood, but quickly leveled off during adolescence. The ability to shift attention was found to be unrelated to processes contributing to global advantage. The results suggest that the ability to flexibly shift attention to and away from local detail, to provide the most adaptive response, continues to develop during childhood into adulthood.

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Heinz Werner’s (1957) orthogenetic principle, that development proceeds from a state of relative diffuse and undifferentiated globality to increasing differentiation, articulation, and hierarchic integration, has been useful for discussions about the relation between global and local processing of visual information in the world (Enns, Burack, Iarocci, & Randolph, 2000). This principle is consistent with the general consensus that general, or global, processing precedes more fine-tuned, local processing at both the microgenetic level of development, in that it is activated first when information is processed, and at the epigenetic level of development, as it reaches adult-like levels earlier in life. The orthogenetic principle is also the conceptual underpinning for the notion that the global-local processing dichotomy might need to be extended to incorporate an even higher developmental process of the integration of information (Burack, Enns, Iarocci, & Randolph, 2000). However, as Werner (1957) argues, the developmental ordering of functions does not imply a circumscribed system in which the later higher-order process is necessarily the one used in a given situation, but rather, greater developmental maturity is essentially characterized by more flexibility in using different processes or operations. Thus, the more developmentally mature person is able to implement the most adaptive function for a given task, regardless of its developmental level. In this study, we assess developmental change in the implementation of global or local visual processing with regard to the ability to switch between levels of processing to provide the most adaptive response rather than with regard to the response that represents the highest developmental level.

Virtually all visual scenes are hierarchically arranged, as they all involve elements that can be processed both individually and globally. A clichéd example of this notion is that of trees and a forest, which can be described as a global arrangement of the trees (Navon, 1977). This phenomenon extends to our entire visual world and ranges in complexity and dynamics. The developmental trajectory of the ability to perceptually organize the elements of visual scenes is informative about the way that children reflect on the world in terms of the relationship of constrained coherent entities (see also Scherf, Behrmann, Kimchi, & Luna, 2009). Thus, the focus of the current article was to examine the development of abilities to flexibly adjust this perceptual organization, between global and local levels of processing, in relation to the changing demands of the environment.

GLOBAL-LOCAL PROCESSING

Global-local processing is typically studied with a paradigm developed by Navon (1977) that involves the identification of hierarchically organized
stimuli, larger (global) letters that are made up of smaller (local) letters that are either the same (congruent) or different (incongruent). On congruent conditions, the critical information at the global and local levels of the hierarchical stimulus entails the same response, whereas on the incongruent conditions, the information at the global and local levels entails competing responses. With various manipulations, this paradigm allows for the examination of three components of attention. One component is referred to as the level of precedence or advantage, as it involves the initial directing of attention to either the global or local level of a stimulus (Navon, 1977). A second component is the susceptibility to interference from irrelevant, but competing, stimulus information (e.g., Raz & Buhle, 2006). The third component is cognitive flexibility that is involved in the shifting of attention between target levels of hierarchical stimuli (e.g., Hübner, 2000). To address the developmental trajectory of the ability to implement the most adaptive function for a task, we used a task-switching paradigm to examine whether, during development from childhood to young adulthood, attentional organization processes that contribute to a global advantage effect and susceptibility to interference are independent from the control mechanisms that contribute to the ability to shift between target levels.

Navon (1977) initially demonstrated that information at the global level of a stimulus was identified faster than the information at the local level. However, this “global advantage” is largely dependent on task characteristics, as a “local advantage” effect can also be elicited with certain manipulations of stimulus features, such as an increase in the overall stimulus size (Enns & Kingstone, 1995; Kimchi, 1992; Kinchla & Wolfe, 1979; Lamb & Robertson, 1990; McLean, 1979; Navon, 1983), a decrease in the number of local elements (Kimchi, 1988; Kimchi, Hadad, Behrmann, & Palmer, 2005; LaGasse, 1993; Martin, 1979), or presentations of the stimulus in the left or right hemi-field (e.g., Delis, Robertson, & Efron, 1986; Kimchi & Merhav, 1991; Lamb, Robertson, & Knight, 1990; Robertson, Lamb, & Knight, 1991). Yet, across a wide range of conditions that are intended to eliminate most confounds, the prevalent finding is that the attention is focused first on the global level (e.g., Goto, Wills, & Lea, 2004; Miller & Navon, 2002; Navon, 2003).

In developmental studies, Werner’s (1948, 1957) “orthogenetic principle” provides a framework for understanding the development of the abilities to integrate the parts and the whole of visual scenes (Burack et al., 2000; Enns et al., 2000; Kimchi et al., 2005). Within this framework, the development of the ability to draw attention to stimuli with multiple levels proceeds from an initially undifferentiated state to one of increasing specialization and finally to the coordinated integration of specialized components (Enns et al., 2000). Thus, as children grow older, the development of the focusing of attention
follows a path from global to local and ultimately to an integrated whole. However, as with adults, the specifics of the developmental trajectories and transitions are largely dependent on task characteristics including the number and size of the stimuli (Enns et al., 2000; Kimchi et al., 2005; for a comprehensive review, see Scherf et al., 2009).

SUSCEPTIBILITY TO INTERFERENCE

Hierarchical target paradigms, as used in the global-local framework, include both a task to perform and a distracting task (i.e., the task to ignore). Hierarchical stimuli are considered congruent when the relevant and the irrelevant level require the same response and are considered incongruent if the relevant and the irrelevant level require a different response. On incongruent trials, information from one level (global or local) interferes with the analysis of information at the other level. The typical finding is that incongruence is associated with slower and less accurate responses, even when the participants are instructed to ignore the distracting aspect of a stimulus (e.g., Fan, McCandliss, Sommer, Raz, & Posner, 2002; Raz & Buhle, 2006; see also Eriksen & Eriksen, 1974). Typically, this interference is asymmetric as irrelevant global information disrupts the task-relevant analysis of local information (i.e., global-local interference), but the local information does not interfere with the processing of global information (e.g., Navon, 1977; see also Kimchi, 1992; Navon, 2003).

FLEXIBLY DIRECTING ATTENTION

The global-local paradigm can also be used to examine the ability to flexibly shift the direction of attention between the global and the local levels of a target stimulus. For example, the participants’ speed in identifying the target stimulus on the second of two successive hierarchical stimulus presentations is considered an index of this ability (e.g., Hübner, 2000; Shedden, Marsman, Paul, & Nelson, 2003; Ward, 1982). This scenario allows for two possible types of sequences. On target repetition sequences, the target level is repeated as the attended-to stimulus remains at the same level of processing, whereas on the level alteration sequences, the target level changes on the second trial. In general, adults’ responses to the second trial are faster in situations with level repetition rather than with level alteration trials (Filoteo, Friedrich, & Stricker, 2001; Hübner, 1997, 2000; Lamb & Yund, 1996, 2000; Robertson, 1996; Shedden et al., 2003; Ward, 1982). These accounts are similar in the sense that they all assume level repetition effects.
that are equal in magnitude (i.e., symmetrical) for both local and global processing. In a comparison of performance in blocks in which attention was fixed at the local or the global level and performance in blocks in which attention switched between global and local levels, Shedden et al. (2003) however, found that the level shifting of adults’ effect requires competition from the distracting (ignored) level and that the nature of the distracting level determines if the level-shifting effect is symmetrical or asymmetrical.

**THE PRESENT STUDY**

The current study included two experiments designed to examine the development from childhood into young adulthood of 1) the direction of attention to either global or local levels of a stimulus (i.e., global or local advantage); 2) the susceptibility to interference; and 3) the flexible direction of attention to global or local levels of hierarchical stimuli. Both experiments involved a binary choice reaction time (RT) task on which children aged 7 and 11 years and young adults were required to respond as fast as possible to the global or the local level of hierarchical stimuli (adapted from Kimchi, 1992; Kimchi & Palmer, 1985). The stimuli at the two levels were congruent on half of the trials and incongruent on the other half (see Figure 1).

In addition, we adopted hybrid versions of the “alternating-runs” and the “explicit task-cuing” procedures from the task-switching literature. The alternating-runs procedure includes “respond-to-global” and “respond-to-local” trials that change predictably every nth trial (e.g., Rogers & Monsell, 1995), whereas the explicit task-cuing procedure involves an initial cue that indicates the task to be performed (e.g., Meiran, 1996; Sudevan & Taylor, 1987). In Experiment 1, the shape of the cue and the target level of the hierarchical stimulus allowed for a physical matching of the cue and the target (see Figure 2). However, as the direct physical match between the cue and the target stimulus might mask the ability to differentiate between the actual conceptualization of the global and the local level of a target stimulus, symbolic cues were used to direct attention to global versus local levels of the target stimulus in Experiment 2 (see Figure 6). The findings from this experiment provided an assessment of the consistency of developmental change in global-local analysis across the two types of cues.

We had three primary hypotheses. First, based on previous reports in which these stimuli yield clear global advantage effects among adults (Kimchi, 1992; Kimchi & Palmer, 1985), the participants were expected to show a global advantage. Consistent with the orthogenetic principle that global processing reaches adult-like levels earlier in life, the global
advantage was expected to be even stronger for children, with the youngest children showing the strongest effect. Secondly, all the age groups were expected to show interference effects when the task was to attend to the local level of incongruent stimuli. Consistent with the orthogenetic principle, this interference effect on local trials was expected to be greatest among the younger children and smallest among the adults (see also Bunge, Dudukovic, Thomason, Vaidya, & Gabrieli, 2002; Konrad et al., 2005; Porporino, Shore, Iarocci, & Burack, 2004; Ridderinkhof & Van der Molen, 1995; Rueda et al., 2004). Thirdly, all of the participants were expected to show higher costs when alternating between target levels than when responding to repeating target levels, regardless of the hierarchical level of the target stimulus. Based on developmental theory and empirical evidence that the ability to switch between two tasks develops gradually during childhood and reaches adult levels of performance at around 12 years of age (e.g., Cepeda, Kramer, & Gonzalez de Sather, 2001; Crone, Bunge, Van der Molen, & Ridderinkhof, 2006; Huizinga, Dolan, & Van der Molen, 2006; but see Kray, Eber, & Lindenberger, 2004), the costs involved in level shifting were expected to be most pronounced among the younger children and least evident among the adult group. This hypothesis can be further specified by positing separate trajectories for each processing level, as reflected in the developmental findings that an adult level of sensitivity is

**FIGURE 1** The target stimuli used in Experiments 1 and 2. A: big square consisting of small squares (congruent); B: big square consisting of small rectangles (incongruent); C: big rectangle consisting of small rectangles (congruent); D: big rectangle consisting of small squares (incongruent).
attained earlier for global than for local target levels (e.g., Burack et al., 2000; Kimchi et al., 2005).

EXPERIMENT 1

Method

Participants

Nineteen (10 female) 7-year-old children, twenty-one (11 female) 11-year-old children, and twenty-one (10 female) young adults were tested. The decision to limit the youngest group to 7-year-olds was based on the consideration that the present task was too difficult for younger children. The children were recruited from regular local public schools in Amsterdam, and the adults were recruited from the University of Amsterdam. The children received a small present for their participation, and the adults received
course credits. Informed consent was obtained for all of the participants, who all reported to be healthy and had normal or corrected-to-normal vision. The Standard Progressive Matrices (SPM; J. C. Raven, Court, & Raven, 1985) was used to obtain an approximate estimate of intellectual level. The scores were converted to quartile scores, following the norms for each age group. There was no significant difference between the age groups on the Raven SPM quartile scores, \(F(2, 58) = 1.27, p = .287\). In addition, chi-square analyses indicated that the gender distribution did not differ significantly between the age groups, \(\chi^2(2) = 0.132, p = .936\). The distribution of age and gender and the Raven quartile scores are presented in Table 1.

### Table 1

<table>
<thead>
<tr>
<th>Age Group</th>
<th>Exp 1 Age</th>
<th>Exp 2 Age</th>
<th>Exp 1 N Female</th>
<th>Exp 2 N Female</th>
<th>Exp 1 Raven Quartile</th>
<th>Exp 2 Raven Quartile</th>
</tr>
</thead>
<tbody>
<tr>
<td>7-year-olds</td>
<td>7;3 (4)</td>
<td>7;5 (8)</td>
<td>10 (9)</td>
<td>15 (9)</td>
<td>3.6 (.49)</td>
<td>2.6 (1.24)</td>
</tr>
<tr>
<td>11-year-olds</td>
<td>11;3 (5)</td>
<td>11;1 (7)</td>
<td>11 (10)</td>
<td>11 (10)</td>
<td>3.5 (.51)</td>
<td>2.7 (.73)</td>
</tr>
<tr>
<td>Young-adults</td>
<td>20;9 (26)</td>
<td>20;11 (29)</td>
<td>10 (11)</td>
<td>13 (9)</td>
<td>3.7 (.46)</td>
<td>2.30 (.66)</td>
</tr>
</tbody>
</table>

Raven Advanced Progressive Matrices (APM) quartile (Raven, Raven, & Court, 1998). Note. Experiment 2 included 11- and young-adults as between-subjects factor in the final analyses.

Apparatus

The tasks were presented on a Toshiba Satellite 1600 laptop (Intel Celeron 800 mHz processor; 15-inch 60-Hz monitor). The response button for the left hand was the “z” key on the computer keyboard, and the response button for the right hand was the “?” key. The responses were counterbalanced across participants.

Stimuli

The target stimuli were geometric figures adapted from studies by Kimchi (1992) and Kimchi and Palmer (1985). The global stimuli were the larger squares or rectangles (93 x 93 pixels or 93 x 189 pixels, respectively) that were made up of smaller “local” stimuli squares or rectangles (21 x 21 pixels or 8 x 46 pixels, respectively). The global square was made up of 16 local squares or 16 local rectangles, whereas the global rectangles were made...
up of 16 local squares or 16 local rectangles. The distance between the local elements was 3 pixels. A schematic of the stimuli is presented in Figure 1.

Procedure

The experimental testing was administered in groups of two participants who were tested in a dimly lit and quiet room (children at school; adults at the university). The Raven SPM (J. C. Raven et al., 1985) was administered to the children as a single group administration in a classroom and to the adults at the end of the test session.

A black horizontal line was presented continuously in the middle of the computer screen against a light-gray background. The target stimuli were presented above or below this line. The participant’s task was to respond to the global (“attend-to-global”) or the local (“attend-to-local”) level of the target stimulus with either a left- or right-hand button press depending on the level indicated by the task cue stimulus. The mapping of the responses onto the stimuli was counterbalanced across participants—with the constraint that the responses to the (small or big) squares was mapped onto one hand, and responding to (small or big) rectangles was mapped onto the other hand for each participant. Half of the trials required a right-hand response; the other half required a left-hand response. In addition, the presentation of the respective tasks above or below the horizontal line was counterbalanced across participants (i.e., “attend-to-global” was presented above the horizontal line and “attend-to-local” was presented below the line, or vice versa).

The global analysis condition was indicated by large cues presented above or below the horizontal line on which the target appeared, whereas the local-analysis condition was indicated by small cues below the horizontal line if the global was above and above the horizontal line when the global was below. The large cues consisted of a big square, which was presented at one side of the target stimulus, and a big rectangle presented at the other side of the target stimulus; the small cues consisted of a small square and a small rectangle. The cues were presented at 1 cm from the target stimulus. The size of global and local cues was the same as the target stimuli, but the global cues did not consist of smaller elements. The color of both the target stimuli and the cues was red (see Figure 2 for an illustration of the cue stimuli relative to the target stimuli).

The time interval between the cue onset and the presentation of the target stimulus varied randomly between 400 and 600 ms (drawn from a uniform distribution). The cue and the target stimuli remained on the screen until the participant’s response. The trial was terminated if no response was elicited after 3,500 ms. A response initiated the cue for the
next trial with a random variable delay of 900 to 1,100 ms (drawn from a uniform distribution). A schematic of the trial sequence is presented in Figure 2.

The participants were administered three blocks of trials, with two “single-level” blocks and one “mixed-level” block. The two “single-level” blocks were presented in random order. In one block (50 trials), the participants performed the local task; and in a second block (50 trials), they performed the global task. In a third, “mixed-level” block (150 trials), the trials alternated between a series of four repetitions of global-directed trials and a series of four repetitions of local-directed trials. The first two blocks were presented in random order, followed by the third block. The experiment was practiced first, with 30 trials in the single-level blocks and 90 trials in the mixed-level block. The participants were instructed to respond as fast as possible while trying to commit the fewest possible errors. Care was taken to ensure that the participants understood the instructions, as indexed by verbal report, response accuracy, and stable RTs.

Design

Both the “single-level” blocks and the “mixed-level” block included “respond-to-global” and “respond-to-local” conditions. In the global conditions, the participants were instructed to respond to the large global shape of the target stimulus (i.e., a square or a rectangle), whereas in the local task, they were instructed to respond to the shape of small elements that comprised the target stimulus (i.e., squares or rectangles). A comparison of performance on the “respond-to-global” trials and the “respond-to-local” trials yielded the global advantage index. In addition, in both the “single-level” blocks and the “mixed-level” block, interference was manipulated by the congruency of the stimuli. Accordingly, the target stimuli were either considered congruent when the global and local levels shared the same shape (square or rectangle) or were considered incongruent when the global and local levels differed in shape. In addition, in the mixed block, the focus was also on two trial types that referred to two different trial sequences of two trials—the current trial and the immediately preceding trial. In this manner, a response could either be preceded by a trial that required a response either to the same task (e.g., “attend-to-global” preceded by “attend-to-global”; i.e., level repetition) or by a trial that required a response to a different task (e.g., “attend-to-global” preceded by “attend-to-local”; i.e., level alternation). A comparison of performance on the level repetition trials and on the level alternation trials yielded the index of shifting attention. See Table 2 for an overview of the goals and the design of the current experiment.
<table>
<thead>
<tr>
<th>Experiments 1 (geometric cues) &amp; 2 (symbolic cues)</th>
<th>Examine developmental change of:</th>
<th>Within-subjects factors</th>
<th>Between-subjects factor</th>
<th>Dependent measures</th>
</tr>
</thead>
</table>
| Single-level blocks 1 & 2 | • global advantage  
• interference effects | • target level (local vs. global)  
• congruence (congruent vs. incongruent) | age group (7 yrs., 11 yrs., young adults) | • square root error percentage  
• median RT (ms) |
| Mixed-level block | • global advantage  
• interference effects  
• flexibly shifting between global and local levels of hierarchical stimuli | • target level (local vs. global)  
• congruence (congruent vs. incongruent)  
• trial type (level repetition vs. level alternation) | age group (7 yrs., 11 yrs., young adults) | • square root error percentage  
• median RT (ms) |

*Note.* Experiment 2 included 11-year-olds and young adults as between-subjects factors in the final analyses.
Results

The results are presented in two sections. In the first section, the focus is on the performance on the single-level blocks. This allows for the examination of developmental change in global advantage and in the susceptibility to between-levels interference. The focus of the second section is the performance in the mixed-level blocks, which allows for an examination of the development of interference effects and of the ability to flexibly shift between global and local levels of hierarchical stimuli. In the analyses, age group (7- and 11-year-old children and young adults) was included as the between-subjects factor. The first five trials in each task block and all trials with RTs shorter than 120 ms were excluded from the analyses. All trials with incorrect response and all trials that followed an incorrect response were excluded from the RT analyses. This amounted to less than 2% of all trials. The main dependent variables were the square roots of the error percentages and the median RTs.

Single-Level Blocks

The square root of error percentages and median RTs were submitted to separate repeated-measures analyses of variance (ANOVAs), with target level (global vs. local) and congruence (congruent vs. incongruent) as within-subjects factors.

Errors. An ANOVA revealed a main effect of target level that reflected global advantage, as indexed by a smaller proportion of errors on global-directed trials compared with local-directed trials (1.8% vs. 2.8%), $F(1, 58) = 5.46, p = .023$, and a main effect of congruence that reflected interference of the irrelevant target level, as indicated by a smaller proportion of errors on congruent trials compared with incongruent trials (1.3% vs. 3.6%), $F(1, 58) = 24.19, p < .0001$. An interaction of target level and congruence revealed an asymmetric effect of interference, as the performance on the local-directed trials suffered more interference from the global level than did the global-directed trials from the local level (3.9% vs. 1%), $F(1, 58) = 7.52, p = .008$. No significant main or interaction effects involving age group were found. Thus, any differences between age groups in RT cannot be interpreted in terms of an accuracy-speed trade-off.

Response latencies. An ANOVA revealed a main effect of age group that reflected shorter RTs among the older children and young adults as compared with the young children (753 ms in 7-year-olds, 504 ms in 11-year-olds, and 367 ms in young adults), $F(2, 58) = 134.78, p < .0001$; a main effect of target level that reflected global advantage, as indicated by
faster responses to the global-directed trials compared with the local-directed trials (503 ms vs. 579 ms), $F(1, 58) = 83.83, p < .0001$; and a main effect of congruence that reflected interference of the nontarget level, as shown by faster responses to the congruent trials compared with the incongruent trials (528 ms vs. 555 ms), $F(1, 58) = 29.42, p < .0001$. Contrary to expectations, no interactions were found between age groups and target level, $F(2, 58) = 1.13, p = .331$, or age groups and congruence ($F < 1$). An interaction of target level and congruence, $F(1, 58) = 4.98, p = .03$, indicated an asymmetric effect of interference, as performance on the local-directed trials suffered more interference than on the global-directed trials (39 ms vs. 17 ms). The interaction of age group, target level, and congruence was not significant ($F < 1$).

**Mixed-Level Block**

In addition to the examination of developmental change in global advantage and susceptibility to interference, the data from the mixed block allowed for an assessment of shifting between levels of attentional processing. Therefore, we compared level repetitions, when the target level on trial N was the same as the target level on trial N-1, with level alternations, when the target level on trial N differed from the target level on trial N-1. The square root of the error percentages and median RTs were submitted to separate repeated-measures ANOVAs with target level (global vs. local), congruence (congruent vs. incongruent), and trial type (level repetition vs. level alternation) as the within-subjects factors.

**Errors.** An ANOVA revealed a main effect of age group, indicating a decrease in errors with age (4.4% for the 7-year-olds, 2.8% for the 11-year-olds, and 1.7% for the young adults), $F(2, 58) = 5.45, p = .007$; a main effect of target level that reflected global advantage, as indicated by fewer errors on global-directed trials compared with local-directed trials (1.2% vs. 3.6%), $F(1, 58) = 13.20, p = .001$; and a main effect of congruence that indicated interference from the nontarget level, as reflected by fewer errors on congruent trials compared with incongruent trials (0.8% vs. 6.1%), $F(1, 58) = 76.01, p < .0001$. No interactions were found for either target level or congruence with age group. The main effect of trial type was not significant, but there was a significant age group × trial type interaction, $F(2, 58) = 3.57, p = .034$ (4.9%, 2.4%, and 2.9% on task alternations and 3.9%, 3.1%, and 0.9% on task repetitions, for 7-year-olds, 11-year-olds, and young adults, respectively). A post-hoc analysis indicated that the effect of trial type was significant only among the adults ($p = .003$). All other effects failed to reach significance.
Response latencies. An ANOVA revealed main effects of age group, indicating shorter RTs with age (894 ms in 7-year-olds, 556 ms in 11-year-olds, and 409 ms in young adults), $F(2, 58) = 121.82, p < .0001$; target level, indicating global advantage, as indexed by faster RTs to global-directed trials compared with local-directed trials (569 ms vs. 670 ms), $F(1, 58) = 130.29, p < .0001$; congruence, indicating interference from the irrelevant target level, as indexed by faster responses to congruent trials compared with the responses on incongruent trials (594 ms vs. 646 ms), $F(1, 58) = 41.19, p < .0001$; and trial type, reflecting that shifting between target levels was associated with a cost, as indicated by faster responses on repetition trials compared with alternation trials (564 ms vs. 675 ms), $F(1, 58) = 152.55, p < .0001$.

An age group $\times$ target level interaction indicated that the responses to global-directed trials were faster than the responses to local-directed trials.

**FIGURE 3** Median RTs (ms) as a function of target level for each age group, in the mixed-level block (Experiment 1). “Local” refers to “attend to local,” and “global” refers to “attend to global.”
in all the age groups. This difference decreased with age (162 ms in 7-year-olds, 89 ms in 11-year-olds, and 50 ms in young adults), \( F(2, 58) = 13.57, p < .0001 \). Subsequent contrast analyses revealed that adult level of performance was attained by the 11-year-olds (see Figure 3).

As anticipated, the age group × congruence interaction revealed a decrease of interference with age (100 ms in 7-year-olds vs. 36 ms in 11-year-olds vs. 16 ms in young adults), \( F(2, 58) = 9.10, p < .0001 \). Subsequent contrast analyses revealed that an adult level of performance was attained by the 11-year-olds. As expected, the age groups differed with respect to the effect of trial type, as indicated by a decrease of level-shifting costs with age (196 ms in 7-year-olds, 79 ms in 11-year-olds, and 57 ms in young adults), \( F(2, 58) = 22.42, p < .0001 \). Subsequent contrast analyses revealed that adult level of performance was attained by the 11-year-olds. Interference on local-directed trials was more pronounced (73 ms) than on global-directed trials (31 ms; target level × congruence; \( F(1, 58) = 9.67, p = .003 \)). Moreover, level-shifting costs on the incongruent trials were higher (135 ms) than on the congruent trials (86 ms; trial type × congruence, \( F(1, 58) = 9.63, p = .003 \)). The age group × trial type interaction was qualified by a higher-order interaction including congruence, \( F(2, 58) = 3.51, p = .036 \). In all of the age groups, a higher cost was associated with level shifting on incongruent trials than with level shifting on congruent trials (see Figure 4). Follow-up contrasts indicated that the increase in level-shifting costs on the incongruent trials discriminated significantly between the groups of children (\( p < .001 \)) but not between the older children and the adult participants. Thus, a global advantage and interference from the nontarget level was on the single-level blocks and in all age groups. The interference effect was asymmetric (i.e., more interference from the global level on local-directed trials than vice versa). In the mixed-level blocks, responses to global-directed trials were faster and interference decreased with age, reaching adult level of performance at age 11 years. Level shifting was associated with a cost in all age groups, and this cost was higher on incongruent trials, as this effect differed significantly between the 7-year-olds and 11-year-olds. We found no evidence for a relationship between target level and trial type during development, suggesting that switching

\[ 1 \text{The finding that adult responses to alternation trials were both more accurate and slower may suggest a trade-off between speed and accuracy. Therefore, for this age group, we performed a follow-up analysis. We split (median) the participants into a low-error group (} N = 10 \text{) and a high-error group (} N = 11 \text{). Subsequently, a } 2 \text{ (error group) } \times 2 \text{ (trial type) } \times 2 \text{ (target level) } \times 2 \text{ (congruence) interaction resulted in nonsignificant interactions with error group (Note: } F < 1 \text{ in the error group } \times \text{trial type interaction). Therefore, we discarded the apparent speed-accuracy trade-off in the trial type effects.} \]
attention from local to global processing takes as much time as shifting from
global to local processing, and this effect is equal in all age groups.

EXPERIMENT 2

The shape of the cue and the target level of the hierarchical stimuli used in
Experiment 1 required the physical matching of the cue and the target stimu-
lus. However, as this direct physical match might mask the account on the
ability to differentiate between the actual conceptualization of the global
and the local level of a target stimulus, symbolic cues were used to direct
attention to global versus local levels of the target stimulus. Thus, the main
goals of Experiment 2 were to examine developmental changes in global
advantage with symbolic cues to indicate the level of analysis (global vs.
local) in responding to the target stimulus, to assess the robustness of the
developmental trajectories of the resistance to interference and the ability
to shift between target levels that emerged in Experiment 1. (See Table 2
for an overview of the goals and the design of the current experiment.)
A cartoon of an elephant was used as the symbolic cue to indicate the
“respond-to-global” task and a cartoon of a mouse was used to indicate

FIGURE 4  Median RTs (ms) as a function of trial type for each age group, on congruent and
on incongruent trials of Experiment 1. “Repetition” refers to repeating choice tasks, and “shift”
refers to shifting choice tasks (i.e., global vs. local, or vice versa).
the “respond-to-local” task. The size of the cues was 4 cm × 2.5 cm. See Figures 5 and 6 for a schematic of the stimulus and cue display. All the other details of the paradigm were the same as in Experiment 1.

Method

Participants

The participants included 24 (15 female) 7-year-old children, 21 (11 female) 11-year-old children, and 22 (13 female) 21-year-old adults. Recruitment of participants, consent procedure, and intelligence estimation were identical to Experiment 1. There were no differences between the age groups on the Raven quartiles, $F(2, 57) = 1.18, p = .316$. Chi-square analyses indicated that the gender distribution did not differ across the age groups, $\chi^2(2) = 0.48, p = .786$. The distribution of gender, age, and Raven scores across age groups is reported in Table 1.

FIGURE 5  The figure displays a trial sequence in Experiment 2. The first display (from left to right) is the last event of the previous trial. Second display: The mouse on the left and the on the right served as cues that instructed the participant to respond by pressing the left key when the target consisted of small squares and by pressing the right key when it consisted of small rectangles. Third display: The target stimulus appears and a response is required. Fourth display: After each response, a response-cue interval occurred, followed by the presentation of a cue (fifth display; elephants indicate press left key for a big square and right key for a big rectangle), and after another interval, the target appeared (sixth display). The fifth display indicates a task shift to global discrimination.
Results

Trial selection before data analysis and the presentation of the results are identical to Experiment 1. The task appeared too difficult for the 7-year-olds, as evidenced by excessive error rates on the incongruent trials, and therefore, they were excluded from the analyses. On the single-level blocks, twelve 7-year-olds performed extremely poorly (i.e., >80% errors) on the incongruent trials (i.e., six failed on the incongruent global-oriented trials and six on the incongruent local-oriented trials). In addition, in the mixed-level blocks condition, another three 7-year-olds displayed extremely high error rates (i.e., >80%) on the incongruent trials, two 7-years-olds failed on the incongruent local-directed trials, and another failed on the incongruent global-directed trials. Accordingly, the 7-year-olds were excluded from the analyses.

Single-Level Blocks

The square root of error percentages and median RTs were submitted to separate repeated-measures ANOVAs, with target level (global vs. local) and congruence (congruent vs. incongruent) as the within-subjects factors.

Errors. The ANOVA revealed main effects of age group, with the young adults committing fewer errors than the 11-year-olds (4.2% among the
11-year-olds and 1.6% among the young-adults, $F(1, 41) = 8.69, p = .005$; and congruence, with fewer errors on the congruent trials compared with the incongruent trials (0.9% vs. 5.6%), $F(1, 41) = 62.12, p < .0001$.

**Response latencies.** The ANOVA yielded main effects of age group, $F(1, 41) = 79.40, p < .0001$, as RTs decreased with age (557 ms in 11-year-olds and 401 ms in young adults); target level, $F(1, 41) = 35.90, p < .0001$, with faster RTs on the global-directed trials than on the local-directed trials (455 ms vs. 502 ms); and congruence, $F(1, 41) = 46.79, p < .0001$, with faster RTs to the congruent trials than to the incongruent trials (464 ms vs. 494 ms). The target level effect reflected a global advantage and the congruence effect reflected interference from the nontarget level. A trend to an age group × congruence effect, $F(1, 41) = 3.09, p = .086$, suggested a possible relation between age and interference. All other effects failed to reach significance.

**Mixed-Level Block**

The square root of the error percentages and median RTs were submitted to separate repeated-measures ANOVAs with target level (global vs. local), congruence (congruent vs. incongruent), and trial type (level repetition vs. level alternation) as the within-subjects factors. Two 11-year-olds were excluded from the analysis due to an extremely high error rate (i.e., >80%) on either the incongruent global-directed trials (one participant) or on the incongruent local-directed trials (one participant). The data from the remaining nineteen 11-year-olds, and twenty-two young-adults were included in the analyses.

**Errors.** The ANOVA yielded main effects of age group, $F(1, 39) = 39.68, p < .0001$, that indicated a decrease in error rates with age (8.8% for the 11-year-olds and 2.9% for the young adults); trial type, $F(1, 39) = 5.20, p = .028$, with fewer errors on level repetition trials (4.7%) compared with level alternation trials (6.3%); and congruence, $F(1, 39) = 186.71, p < .0001$, with fewer errors on the congruent than on the incongruent trials (1.0% vs. 13.5%). Two-way interactions were found for age group × congruence ($F(1, 39) = 8.00, p = .007$) and for congruence × trial type ($F(1, 39) = 23.15, p < .0001$). The age group × congruence interaction indicated that interference decreased with age (19.2% for the 11-year-olds and 7.3% for the young adults). The congruence × trial type interaction indicated that interference on shift trials was more pronounced than on the repetition trials (17.2% vs. 8.4%). A three-way age group × trial type × congruence interaction, $F(1, 39) = 9.94, p = .003$, revealed a marginally higher cost associated
with level shifting on the congruent trials than on the incongruent trials (0.8% vs. 1.6%) for the 11-year-olds and a marginally higher cost associated with level shifting on the incongruent trials than on the congruent trials (0.6% vs. 0.1%) among the young adults.

**Response latencies (RTs).** The ANOVA revealed main effects of age group, $F(1, 39) = 30.49, p < .0001$, as RTs decreased with age (691 ms for the 11-year-olds and 501 ms for the young adults); target level, $F(1, 39) = 48.41, p < .0001$, as reflected by faster RTs to the local-directed trials (570 ms) than to the global-directed trials (623 ms); congruence, $F(1, 39) = 58.29, p < .0001$, as indicated by faster RTs to the congruent as compared with the incongruent trials (638 ms vs. 555 ms); and trial type, $F(1, 39) = 125.0, p < .0001$, as indicated by faster RTs on target repetition trials (498 ms) than on target alternation trials (695 ms).

An age group × congruence interaction, $F(1, 39) = 9.68, p = .003$, was found, with slower RTs (116 ms for the 11-year-olds and 49 ms for the young adults) to the incongruent trials compared with the congruent trials. An age group × trial type interaction, $F(1, 39) = 7.27, p = .010$, revealed that the costs of shifting between levels decreased with age (244 ms for the 11-year-olds and 149 ms for the young adults). A trial type × congruence interaction, $F(1, 39) = 13.86, p = .001$, revealed that the overall costs of shifting were higher on the incongruent trials (236 ms) than on the congruent trials (156 ms). Finally, the ANOVA yielded a significant interaction of age group, congruence, and trial type, $F(1, 39) = 4.51, p = .040$, with a higher cost associated with level shifting on the incongruent trials than on the congruent trials in both age groups, although the magnitude of this effect decreased with age (for the 11-year-olds, 307 ms vs. 181 ms; and for young adults, 166 ms vs. 132 ms; see Figure 7).

Thus, global advantage and interference from the nontarget level were found in the single-level blocks across the age groups. An age-related decrease in the sensitivity to interference almost reached significance. In the mixed-level blocks, both the 11-year-olds and the young adults showed a global advantage. Interference from the nontarget level was found in both age groups, but this effect decreased with age from 11 years to young adulthood. Level shifting was associated with a cost that decreased with age between 11 years and young adulthood and was most prominent on incongruent trials. As in Experiment 1, we found no evidence of a relation between target level and trial type for the two age groups. Thus, costs for shifting between target levels are symmetrical (i.e., it takes equally long to switch from local to global or the other way around). Thus, the ability to flexibly switch attention between local and global processing seems to be independent from processes that contribute to global advantage.
An additional set of analyses was performed to examine the consistency of age effects across the two experiments. The ANOVAs included age group (11-year-olds and young adults) and Experiment (1 and 2) as between-subjects factors. The results indicated that the findings from Experiments 1 and 2 are consistent, as the global advantage effect was generally evident in both experiments, although more pronounced in Experiment 1 (78 ms in Experiment 1 vs. 46 ms in Experiment 2, $F(1, 81) = 9.09, p = .003$). The effect of congruence was evident in both experiments, although it was more pronounced in Experiment 2, particularly among the children (in Experiment 1, 36 ms for the 11-year-olds vs. 19 ms for the young adults; in Experiment 2, 116 ms for 11-year-olds vs. 49 ms for the young adults, $F(1, 79) = 4.83, p = .031$). The effect of shifting between target levels was also present in both experiments, $F(1, 79) = 47.80, p < .0001$, and was moderated by the effect of interference, $F(1, 79) = 7.06, p = .01$, and nearly significantly by age.
\(F(1, 79) = 3.84, p = .053\). Subsequent analyses revealed that the shifting between levels was associated with a cost in RT for both age groups and experiments, as reflected by larger RTs on the alternation trials compared with the repetition trials. These level-shifting costs did not differ between the age groups in Experiment 1 but did in Experiment 2 as they were larger among the 11-year-olds (244 ms) compared with the young adults (149 ms). The lack of a relation between target level and trial type suggests that performance costs as a result of shifting attention between global and local processing are similar.

**DISCUSSION**

The goal of this study was to examine the developmental change in the ability to switch between levels of global and local visual processing to provide the most adaptive response. Participants of the ages of approximately 7 years, 11 years, and 21 years performed a task that allowed for the examination of 1) the direction of attention to either global or local levels of a stimulus (i.e., global or local advantage); 2) the susceptibility to interference; and 3) the flexible direction of attention to global or local levels of hierarchical stimuli. The task involved a typical global-local paradigm, including target stimuli adapted from Kimchi (1992; Kimchi & Palmer, 1985), with a hybrid version of the “alternating-runs” and the “explicit task-cuing” procedures from the task-switching literature (e.g., Meiran, 1996; Rogers & Monsell, 1995). The current study entailed two experiments. In Experiment 1, participants were presented with trials in which the shape of the cue and the target level of the hierarchical stimulus allowed for a physical matching of the cue and the target. This direct physical match between the cue and the target stimulus may have masked the ability to differentiate between the actual conceptualization of the global and the local level of a target stimulus; therefore, symbolic cues were used to direct attention to global versus local levels of the target stimulus in Experiment 2. The findings from the second experiment allowed for the assessment of the consistency of developmental change in shifting between global-local analysis across the two types of cues. In both experiments, the participants were first presented with two blocks in which attention was fixed either at the local or at the global level, followed with a block in which attention was manipulated so that it shifted between global and local levels.

**Fixed Attention at Global or Local Processing**

Consistent with the common observation of a global advantage effect that is commonly found among adults with the target stimuli that were used in this
study (e.g., Kimchi, 1992; Kimchi & Palmer, 1985), we found a global advantage effect among all age groups. The responses to the global-oriented trials were faster and more accurate compared with the responses to the local-oriented trials. This finding is consistent with the considerable evidence of global precedence that is found in typical adults (e.g., Enns et al., 2000; Goto et al., 2004; Miller & Navon, 2002; Navon, 2003). In addition, based on previous findings among adults, we predicted interference of irrelevant information on the incongruent trials (e.g., Kimchi, 1992; Navon, 1977). As expected, in both experiments, the responses were slower on the incongruent as compared with the congruent trials in all age groups. This interference effect was asymmetrical, as the responses to the local target level were more affected by irrelevant information from the nontarget level than were the responses to the global target level of the hierarchical stimuli. Thus, task performance was affected by the interference of information from the nontarget level, and this effect was strongest on the trials that required local analysis.

Our hypotheses of developmental change were guided by the “orthogenetic principle” (Werner, 1948/1957), in which the processing of hierarchical stimuli in children follows a global-to-local pathway as they grow older. Within this framework, young children process a hierarchical stimulus in an undifferentiated state as a global whole, whereas the processing of older children entails a more coordinated integration of the specialized components of the local parts (Enns et al., 2000). Thus, we anticipated a global advantage for all groups that would be strongest with the youngest children (e.g., Burack et al., 2000; Enns et al., 2000; Kimchi et al., 2005; Porporino et al., 2004; Scherf et al., 2009). Moreover, based on the developmental literature (e.g., Bunge et al., 2002; Konrad et al., 2005; Porporino et al., 2004; Ridderinkhof & Van der Molen, 1995; Rueda et al., 2004), we expected the susceptibility to interference of the irrelevant stimulus level would decrease with age. However, no age-related decrease of either the global advantage effect or the interference effect was evident in the blocks that required fixed attention to either the global or the local level of a stimulus. These findings might be explained within the context of selective attention in global-local processing as forwarded by Plaisted, Swettenham, and Rees (1999) in their study of hierarchical processing in children with autism and typically developing children around the age of 10 years. In a selective attention procedure, the children were instructed to the level of processing (global or local) to which the target stimulus would appear. Both the groups showed a global advantage effect and an asymmetric interference effect (faster RTs and increased accuracy on global trials) on the selective attention task. Thus, the current findings suggest that in all age groups, the global level of a stimulus is perceived first
compared with the local level, and this effect is unrelated to interference of
the irrelevant stimulus level.

**Shifting Attention Between Global and Local Processing**

In contrast to the findings from the fixed-attention blocks, but as expected,
the global advantage effect was found in all the groups in both of the experi-
ments and decreased with age. In addition, as expected, the interference
effect decreased in strength with age. Thus, the global advantage and inter-
ference effects were greatest when the task required the alternation between
two tasks, and these effects decreased with age. These findings were present
only in the mixed-level blocks, suggesting that they suggest an increased sal-
ience of the hierarchical structure of the stimuli, which then leads to greater
difficulty for the children to process a hierarchical stimulus as a global
whole. This is in accord with the notion that the global-local processing
dichotomy possibly needs to be extended to incorporate the even higher
developmental process of the integration of information (Burack et al.,
2000), while greater developmental maturity is characterized by more flexi-
bility in using different processes or operations (Werner, 1957). Similarly,
one could argue that children are less able to implement the rules when
challenged with a task, especially when the task requires the actual shifting
between target levels. This observation is consistent with Zelazo, Mueller,
Frye, and Marcovitch’s (2003) findings from a study of planning in which
children initially learned rules but were only later able to switch between
conflicting rules. Thus, the ability to use rules becomes both more efficient
and adaptive with development (Burack, Russo, Dawkins, & Huizinga,
2010), even when the rule is already learned (see also Diamond & Kirkham,
2005).

Consistent with previous evidence from global-local task-switching
among adults (e.g., Hübner, 2000; Monsell, 2003; Shedden et al., 2003),
the level-alternating responses were slower and less accurate than level-
repetition responses in both experiments. The costs of level shifting were
greater on the incongruent than on the congruent trials, as the responses
were slower when the level at which the target was presented on the current
trial was different from the level on the previous trial. This pattern of find-
ings is consistent with the evidence that the size of level repetition effects
depends on competition from the level that is ignored (Shedden et al., 2003).

The costs related to level shifting decreased from 7 to 11 years, reaching
an adult level of performance by the age of 11 years (in Experiment 1; the
7-year-olds were excluded from Experiment 2). This developmental pattern
of change in level-shifting costs was consistent with evidence from the devel-
opmental literature on task switching in children showing that the cost of
switching between rules of behavior decreased until the age of about 12 (e.g., Cepeda et al., 2001; Crone et al., 2006; Huizinga et al., 2006). In accord with previous findings that the costs associated with shifting from local to global and global to local are symmetrical, the age-related decrease in the costs involved in level shifting was not affected by target level (e.g., Lamb & Yund, 1996; Robertson, 1996; Ward, 1982; but see Shedden et al., 2003).

In contrast to target level, the effect of congruence was associated with age-related change in level shifting, as the performance of the 7-year-old children suffered more from the need to shift levels on the incongruent than on the congruent trials. This finding supports the notion that young children are more susceptible to interference from the to-be-ignored level (e.g., Bunge et al., 2002; Dempster, 1993; Ridderinkhof & Van der Molen, 1995). When 7- and 11-year-old children need to shift between tasks related to hierarchical stimuli, their performance is not affected by the actual level to which they must attend. Evidently, their performance suffers from interference from the to-be-ignored target level, suggesting that 7- and 11-year-old children are able to simultaneously hold more than one rule in mind and can shift between these rules but experience difficulty resisting task-irrelevant information when shifting between the levels.

Consistency Between the Experiments

The two experiments were the same except for the cues used to indicate target level. The experiments included different participant groups (but age and gender did not differ between experiments). In Experiment 1, the cues repeated the target-response mapping. That is, the cues were shapes (squares or rectangles) of a size corresponding to that of the respective target pattern. These cues were used to allow the participants to focus their attention to the specified level in advance of the presentation of the target stimulus. In Experiment 2, the cues did not repeat the target-response mapping. More specifically, the cues were cartoons of an elephant (indicating the global level) and of a mouse (indicating the local level). The participants needed to translate the cartoon into a category code indicating target level, thereby posing a greater account on the actual conceptualization of the local and the global level of the stimulus.

Overall, the outcomes of the consistency check indicated that the basic patterns of the findings were similar across the two experiments. A global advantage effect, a global-to-local interference effect, and a level repetition effect were all found in both experiments. The major difference between the experiments was in the performance of the 7-year-old children who were able to perform well on Experiment 1 but committed so many errors on the incongruent condition on Experiment 2 that only about half of them
were deemed able to perform adequately on the task. Thus, the inability of half of the young children to respond accurately suggests that they are able to process the symbolic cues but were unable to use the meaning in the face of discrepant information. The ability to complete the task accurately was not predicted by intellectual level as indexed by the Raven scores.

A tentative interpretation of the trial-specific failure of the 7-year-old group is that the task demands of Experiment 2 on working memory exceeded those available for this group. In Experiment 1, in each task block, the mapping was refreshed on each trial (i.e., match target to cue), and the participants could use the size of the cue for directing attention to the corresponding level. In Experiment 2, the participants needed to retain the target-response mapping in working memory, while the cartoon was translated into a category code. In Experiment 2, the participants could ignore the cue on single-level trials, as only one task set had to be activated. However, in the mixed-level blocks, they needed to keep two sets active in working memory, as changing from one set to another (i.e., set shifting) requires the ability to flexibly activate (and deactivate) the respective tasks. The selective failure on incongruent trials can then be explained by suggestions that the ability to inhibit is inversely proportional to the availability of working memory (e.g., Bjorklund & Harnishfeger, 1990; Kipp, 2005). The target at the to-be-attended level and the information at the to-be-ignored level activated competing responses (e.g., Ridderinkhof & Van der Molen, 1995), and the participants needed to inhibit the current response to the information at the to-be-ignored level. Inhibition is more difficult for younger children of around age 7 years (Van den Wildenberg & Van der Molen, 2004), as compared with older children and young adults, particularly when their working memory is loaded (e.g., Eenshuistra, Ridderinkhof, & Van der Molen, 2004).

CONCLUSION

In conclusion, the focus of the current study was an examination of the development of 1) the direction of attention to either global or local levels of a stimulus (i.e., global or local advantage); 2) the susceptibility to interference; and 3) the flexible direction of attention to global or local levels of hierarchical stimuli. The findings indicated a global advantage effect in all age groups and a trend toward local processing from 7 years to young adulthood. The susceptibility to irrelevant information decreased with age, whereas the ability to flexibly shift between global-local levels increased. Young adult levels of both these abilities were not yet attained by 11 years of age. The findings suggest that, in accord with Werner’s orthogenetic
principle, processing hierarchical stimuli eventually involves the integration of the specialized components of the local parts of a stimulus as the ability to flexibly shift attention to and away from local detail to provide the most adaptive response continues to develop during childhood into adulthood.

REFERENCES


