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To cite this article: Marie T. Banich , Alessandra M. Passarotti & Dana Janes (2000) Interhemispheric Interaction During Childhood: I. Neurologically Intact Children, *Developmental Neuropsychology*, 18:1, 33-51, DOI: [10.1207/S15326942DN1801\\_3](https://doi.org/10.1207/S15326942DN1801_3)

To link to this article: [https://doi.org/10.1207/S15326942DN1801\\_3](https://doi.org/10.1207/S15326942DN1801_3)



Published online: 08 Jun 2010.



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# Interhemispheric Interaction During Childhood: I. Neurologically Intact Children

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This study examined the development of interaction between the hemispheres as a function of computational complexity (Banich & Belger, 1990; Belger & Banich, 1992) in 24 children aged 6.5 to 14 years. Participants performed 2 tasks: a less complex physical-identity task and a more complex name-identity task. Children, like adults, exhibit an across-hemisphere advantage on the computationally more complex name-identity task, and neither a within- nor an across-hemisphere advantage for the computationally less complex physical-identity task. Correlations indicated that the younger the child, (a) the greater the size of the within-hemisphere advantage on the less complex task, (b) the greater the size of the across-hemisphere advantage on the more complex task, and (c) the poorer the ability to ignore attentionally distracting information in a selective attention paradigm. These results suggest that interhemispheric interaction in children, like that in adults, serves to deal with the heightened processing demands imposed by increased computational complexity.

In this article, we examine whether functional interaction between the hemispheres changes during childhood. This question is of interest because the corpus callosum, the nerve fiber tract providing cortical connections between the hemispheres and the major conduit for interhemispheric interaction, continues to myelinate up until the early adult years (Giedd et al., 1996). Myelination is the process whereby glial cells form a fatty insulating sheath around axons, allowing for faster conduction of neural impulses. Increased myelination of the callosum throughout childhood increases the speed of neural transmission and implies that the efficiency of interhemispheric communication increases during this developmental period.

A number of different approaches have been taken to examine whether the functional connectivity between the hemispheres indeed increases with age (for a review, see Hagelthorn, Brown, Amano, & Asarnow, this issue). Some researchers have examined whether the speed of callosal transmission decreases with age. For example, a subset of investigators examined whether estimates of interhemispheric transfer time, as derived from behavioral measures (e.g., Brizzolara, Ferretti, Brovendani, Casalini, & Sbrana, 1994; Ratinckx, Brysbaert, & d'Ydewalle, 1997) or evoked potentials (e.g., Hagelthorn et al., this issue; Salamy, 1978) to simple stimuli such as light flashes, change with age. Others used behavioral tasks to examine developmental changes in the ability to compare stimuli across the hemispheres (e.g., O'Leary, 1980; Quinn & Geffen, 1986). Still others examined the degree to which the hemispheres can work independently of one another in childhood, from both a cross-sectional (Merola & Liederman, 1985) and a longitudinal (e.g., Liederman, Merola, & Hoffman, 1986) perspective. The results of these studies are not always uniform, but on the whole, they suggest that functional connectivity between the hemispheres increases with age.

In this study, we examined the possibility that interhemispheric interaction works in much the same manner in the developing brain as it does in the adult brain. In particular, we believe that it provides a means to deal with increases in attentional demands and task complexity (for a review, see Banich, 1998). To vary computational complexity, we compare performance on two tasks. In general, our less complex task is a physical-identity task in which individuals decide if either of two probe items, one presented in each visual field, is physically identical to a laterally presented target item. The more complex task is generally a name-identity task. Here, individuals decide if either of two laterally presented uppercase probe letters has the same name as a laterally presented lowercase target item. The name-identity task is more computationally complex than the physical-identity task, because in addition to the demands of perceptual processing and decision making (as for the physical-identity task), one must also perform a case or name translation to determine if two letters match.

To investigate the effects of interhemispheric interaction, we compared performance on these tasks for two types of trials: within-hemisphere trials and across-hemisphere trials. On within-hemisphere trials, the target and matching

probe are presented in the same visual field, and hence to the same hemisphere. Under such conditions, no interhemispheric interaction is necessary for a decision to be reached. In contrast, on across-hemisphere trials, the target and matching probe are presented in opposite visual fields. In this case, interhemispheric interaction must occur if the correct decision is to be reached.

We assume that the comparison of the two items depends mainly on the callosum, because split-brain patients are unable to produce correct match decisions when information is presented in opposite visual fields (e.g., Sergent, 1990; Sperry, Gazzaniga, & Bogen, 1969). Although recent work suggested that transfer of letters can be accomplished by acallosal individuals via the anterior commissure (Brown, Jeeves, Dietrich, & Burnison, 1999), we assumed that this channel plays a minor role in individuals who have an intact callosum, because it cannot support the transfer of such information under complex conditions.

In adults, we typically observe that across-hemisphere processing is more advantageous for computationally complex tasks than for less complex tasks (e.g., Banich & Belger, 1990; Banich, Stolar, Heller, & Goldman, 1992; Belger & Banich, 1992, 1998; Weissman & Banich, 1999). We interpreted these results as indicating an advantage to dividing processing across the hemispheres as task complexity increases. More specifically, when a task is computationally simple, it seems that the resources of one hemisphere are not overly taxed. In fact, the additional step of integrating information across the hemispheres actually appears to be detrimental to performance, because it adds a communication "overhead." In contrast, as tasks become more complex, the computational advantage afforded by dividing processing between the hemispheres more than offsets the additional cost of communication between them.

In this study, we examined whether a similar pattern would be observed in school-age children. Findings from a number of studies suggest that important developmental changes in interhemispheric integration occur between the ages of 9 and 11 years (e.g., Merola & Liederman, 1985), and hence our study centered on this age range.

There are a number of ways in which interhemispheric interaction may change as a function of computational complexity during development. One possibility is that there is little developmental change in this aspect of interhemispheric interaction. As reviewed elsewhere (Banich, 1998), we have argued that our results indicate a general processing advantage for dividing processing across the hemispheres when tasks are complex. In effect, we believe the effect is one of "mass action." The reasons for this conclusion are that the effect is observed across a variety of tasks (e.g., Banich & Passarotti, 2000; Weissman & Banich, 1999), response parameters (e.g., Banich & Passarotti, 2000), and modalities (e.g., Passarotti & Banich, 2000). Such an effect may not be influenced by the main developmental change in interhemispheric interaction, which is the decreased speed with which neural signals are transferred across the callosum. All that may matter would be

whether a division of processing across the hemispheres is possible. Because children clearly are able to integrate information between the hemispheres (unlike split-brain patients), they may exhibit a pattern similar to adults.

Another possibility is that decreases in callosal transfer time with age may reduce the cost or overhead associated with interhemispheric communication. If this were the case, we would expect the relative advantage of across-hemisphere processing to increase with age. A final possibility is that interhemispheric processing may be more advantageous for younger than for older children. This result may be expected if one considers that interhemispheric interaction is especially useful under demanding conditions. Because younger children do not have the processing capacity of older children, they may rely more on across-hemisphere processing when dealing with increased processing demands. Such an effect would be most pronounced in the name-identity task, because it is computationally more complex.

Although this last prediction may seem counterintuitive, support for this possibility has been provided by work with older adults. There is much evidence that the cognitive processing capacity of older adults decreases with age (e.g., see Park & Schwarz, 2000). Recently, findings indicate that older adults exhibit a greater across-hemisphere advantage at lower levels of complexity than do younger adults (Reuter-Lorenz & Stanczak, *this issue*; Reuter-Lorenz, Stanczak, & Miller, 1999). Hence, older adults may rely on interhemispheric interaction as a compensatory mechanism to help deal with their diminished ability to cope with increased task complexity. A similar phenomenon may be observed in young children as well.

Another issue we wished to examine was whether there is a relation between certain aspects of attentional functioning and developmental aspects of interhemispheric interaction. Attention is a multifaceted entity encompassing many different processes including vigilance (sustained attention), selective attention with regard to spatial location or item attributes (e.g., color, form), response selection, and the management or allocation of resources required to successfully perform a task (e.g., LaBerge, 1990). As discussed previously, interaction between the hemispheres appears to modulate the information-processing capacity of the brain and as such can be considered an attentional function because it is a process that modulates the allocation of resources (for a review, see Banich, 1998).

The research examining a possible linkage between attentional functioning and developmental changes in interhemispheric interaction is relatively scant. However, one aspect of attention, sustained attention, has been linked to developmental changes in interchange between the hemispheres. Rueckert, Sorensen, and Levy (1994) showed that better performance on an interhemispheric matching task in children predicted better performance on a vigilance task. The interhemispheric task required individuals to compare lines on one, two, or three of the following dimensions: length, color, and orientation. In the within-hemisphere condition, the lines were presented to the same hemisphere, whereas in the across-hemisphere condition, the lines were presented to opposite hemispheres. In the vigilance task,

individuals attended to a box and responded each time a briefly presented *X* appeared in the box. The authors found that children who were faster on across- than within-hemisphere processing were also generally faster on the vigilance task.

In a follow-up study, Rueckert and Levy (1996) found that better attentional performance was significantly correlated with less interhemispheric interference between motor programs. In particular, they examined the degree of interference that occurred when children were asked to draw a circle with one hand and a straight line with the other, as compared with the interference that occurred when drawing the same item with both hands. Children who exhibited higher levels of interference when drawing different items with each hand also exhibited deficits in sustained attention, especially at longer interstimulus intervals (i.e., 18 sec).

In this study, we wished to examine the relation between the degree to which interhemispheric processing helps the brain deal with computational complexity and another aspect of attention, selective attention for perceptual information. This exploration is motivated by our work with adults suggesting that selection of perceptual information can be modulated by interhemispheric interaction. For example, we have shown that interference between the local and global aspects of a hierarchically organized figure (e.g., a big *H* composed of little *S*s) can be reduced when the two items to be compared are initially directed to different hemispheres as opposed to being directed at a single hemisphere (Weissman & Banich, 1999). In this study, we were able to demonstrate that at least a portion of this modulation occurred at the level of perceptual selection. We found that interhemispheric interaction reduced interference more when the stimuli were composed of few local items, which made it harder perceptually to parse local and global information (Kimchi & Palmer, 1985), as compared to when the stimuli were composed of many local items, which allowed for an easier segregation.

Converging evidence for the role of interhemispheric interaction in the selection of perceptual information is provided by a study from our laboratory employing a lateralized version of the Stroop task in which a word is presented in one visual field and a color bar in the other. The individual's task is to name the color of a bar (e.g., red) while ignoring whether the word would facilitate (e.g., when the word is *red*) or interfere with such a response (e.g., when the word is *blue*). The closer the word is to the bar, the greater the interference provided by the word (e.g., Lowe & Mitterer, 1982). This finding suggests that a perceptual factor (i.e., the distance between the word and bar) influences how difficult it is to attentionally select the relevant information and block out conflicting information. In our study we had the word positioned either relatively close to the bar (2.9°) or further away (4.9°). We found that when the bar was closer to but not further from the word, the relative advantage of callosal transfer of information depended on attentional demands—whether the word's identity facilitated or interfered with performance. Because the effect of interhemispheric interaction varied with a perceptual factor,

these results are consistent with Weissman and Banich (1999) in suggesting that interhemispheric interaction can modulate the selection of perceptual information.

If interaction between the hemispheres can modulate selective attention in adults, it would be of interest to know whether developmental changes in interhemispheric interaction would be associated with developmental changes in selective attention. To investigate this issue, we had children perform a free-vision version of a lateralized selective attention task that we have previously used with adults (Banich & Passarotti, 2000). This task requires selective attention, because the participants make a match decision based on the shape of items while ignoring their colors. Three items are presented on each trial, a target item and two probes. Participants decide if the target item matches one of the two probes in shape. To vary attentional demands, we manipulate the relation between the target and probes with regard to the attribute that is to be ignored (e.g., color). In conditions in which attentional demands are low, color information is congruent with form information (i.e., matching forms are the same color, mismatching forms are different colors). In contrast, in conditions in which attentional demands are high, color provides discordant information (i.e., matching forms are different colors, mismatching forms are the same color).

With adults, we found that the interfering effect of color could be modulated by interhemispheric interaction. That is, when matching items were presented in different visual fields as compared with the same visual field, the interfering effect of color was diminished. Hence, we have reason to believe that the ability to selectively attend to one item attribute over another (i.e., attend to form and not color) was aided by a division of processing between the hemispheres. Because performance on this task was modulated by interhemispheric interaction in adults, we reasoned that it was a good candidate task to employ with children.

In this study, we gave children a nonlateralized version of this task as a means of assessing selective attention without regard to within- or across-hemisphere processing. We then examined whether there was a relation between performance on this selective attention task and the tasks that we typically employ to examine interhemispheric interaction (i.e., the physical- and name-identity tasks). We reasoned that if interaction between the hemispheres helps increase the capacity for selective attention during development, we should observe a relation between the performances on the attentional and interhemispheric tasks.

## METHOD

### Participants

Twenty-four children between the ages of 6 and 14 years were recruited through school districts in the Champaign–Urbana area. Using a median split, the children

were divided into two equal groups. The younger group included all children less than 10.5 years of age, and the older group included all children older than 10.5 years of age. All children were right-handed, had normal visual acuity, lacked a lateral phoria, and were not color-blind. Children with a history of learning disability were excluded from the sample.

## Tasks

All children performed both the interhemispheric interaction and selective attention tasks.

### *Interhemispheric Task*

*Stimuli.* Stimuli were the uppercase and lowercase versions of the letters *A*, *B*, *D*, *G*, *H*, *E*, *F*, *L*, *R*, *M*, *T*, and *Q* presented in Chicago font. Each display contained three black letters on a white background. Each letter subtended no more than  $0.95^\circ$  horizontally and  $1.3^\circ$  vertically. The two probe items were centered  $1.6^\circ$  above fixation and  $2.68^\circ$  laterally from midline, one in each visual field. The target item was centered  $1.6^\circ$  below fixation and  $1.6^\circ$  laterally from midline. For the physical-identity task, all items were uppercase letters. For the name-identity task, the two probes were presented in uppercase, and the target was presented in lowercase.

Half of all trials were match trials, in which one of the probes matched the target item, and half were mismatch trials, in which all three letters were different. For match trials, half were within-hemisphere trials, in which the target and the matching probe were presented in the same visual field, and half were across-hemisphere trials, in which the target and matching probe were presented in opposite visual fields. Within each of these conditions, the target was presented in the left visual field (LVF) for one half of the trials and in the right visual field (RVF) for the other half of the trials. Likewise for mismatch trials, the target appeared equally often in the LVF and RVF (see Figure 1).

*Procedure.* For each task, individuals received 20 practice trials and 120 test trials, which were divided into three blocks of 40 trials. The physical-identity task always preceded the name-identity task. At the beginning of a trial, a black square appeared for 300 msec; the abrupt onset of the square served to draw attention to this fixation point. Next, the three letters (along with a smaller fixation square) were displayed for 200 msec. After the stimulus display occurred, a blank white screen was displayed for 3,000 msec, during which time children were asked to press the space bar if there was a match and to refrain from responding if there was no match (go–no-go responses). Reaction time (RT) was recorded for each matching trial. This task required approximately 45 min for completion.



## Physical-Identity Task

### Match Trials

<u>Within LVF</u>		<u>Within RVF</u>		<u>Across Probe RVF</u>		<u>Across Probe LVF</u>
<b>B</b>		<b>T</b>		<b>T</b>		<b>B</b>
	•		•		•	
<b>B</b>			<b>T</b>	<b>B</b>		<b>T</b>

### Mismatch Trials

<u>LVF</u>		<u>RVF</u>
<b>R</b>		<b>M</b>
	•	
<b>F</b>		<b>F</b>

## Name-Identity Task

### Match Trials

<u>Within LVF</u>		<u>Within RVF</u>		<u>Across Probe RVF</u>		<u>Across Probe LVF</u>
<b>B</b>		<b>T</b>		<b>T</b>		<b>B</b>
	•		•		•	
<b>b</b>			<b>t</b>	<b>t</b>		<b>b</b>

### Mismatch Trials

<u>LVF</u>		<u>RVF</u>
<b>R</b>		<b>M</b>
	•	
<b>f</b>		<b>f</b>

FIGURE 1 Sample match and mismatch trials for the interhemispheric task. *Note.* LVF = left visual field; RVF = right visual field.

### *Selective Attention Task*

**Stimuli.** The stimulus array consisted of three geometric shapes arranged in the configuration of an inverted scalene triangle. We employed 16 colored shapes, which were created with the graphic software Adobe Photoshop 2.0.1. We used four exemplars of each of four shape categories: rectangles, ovals, triangles, and diamonds. All shapes covered an area of 0.25 cm<sup>2</sup> so that surface area would not provide a way to distinguish between them. The shapes subtended a maximum of 0.70° horizontally and 1.7° vertically. All shapes were colored, with four gradations for each of four color categories: green, brown, purple, and blue.

In our experimental array, the two probe items were always different shapes from each other. They were equally distant from the fixation point (2.8° lateral) and equally above it (1.4°). The bottom target item appeared at the same distance from the fixation cross (1.4°) as the top probe items, but laterally it was closer to fixation (1.4°) than the top probe items were. On half of the trials (match trials), the target shape was identical to one of the two probe shapes (e.g., both were equilateral triangles), and on one half of the trials (mismatch trials), the target was identical to neither shape. The bottom target was presented on the left for one half of the trials and on the right for the other half. Mismatch trials were constructed so that in one half of trials, all the items were different, but the target and one of the probes belonged to the same form category (e.g., an equilateral and an isosceles triangle). In the remaining half, each item was from a different form category.

To study selective attention, we varied the degree to which color facilitated or interfered with making the physical-identity decision. On one half of the match trials, the target and the same-form probe were identical in color (e.g., both midnight blue), and on one half they were from different color categories (e.g., midnight blue and lime green). Within each of these categories, trials were further divided so that on one half of the trials the different-form probe was identical in color to the target item (e.g., both were lime green), and on one half it was from a different color category. This arrangement provided for four different types of match trials, which can be considered to vary along a continuum in terms of the degree of selective attention required (see Figure 2).

In the first category of trials, the least selective attention was required, because the same-form probe matched the target in color (facilitating the decision that the probe matched the target) and because the different-form probe mismatched the target in color (helping to identify that probe as not matching the target). These trials were 16.7% of all match trials. In the second and third category of trials, an intermediate degree of selective attention was required. In the second category of trials, the same-form probe was different in color from the target (hindering recognition of the match in form), and the different-form probe was also distinct in color from the target (helping to identify that probe as not matching the target). These trials made up 33.3% of all match trials. In the third category, the same-form probe

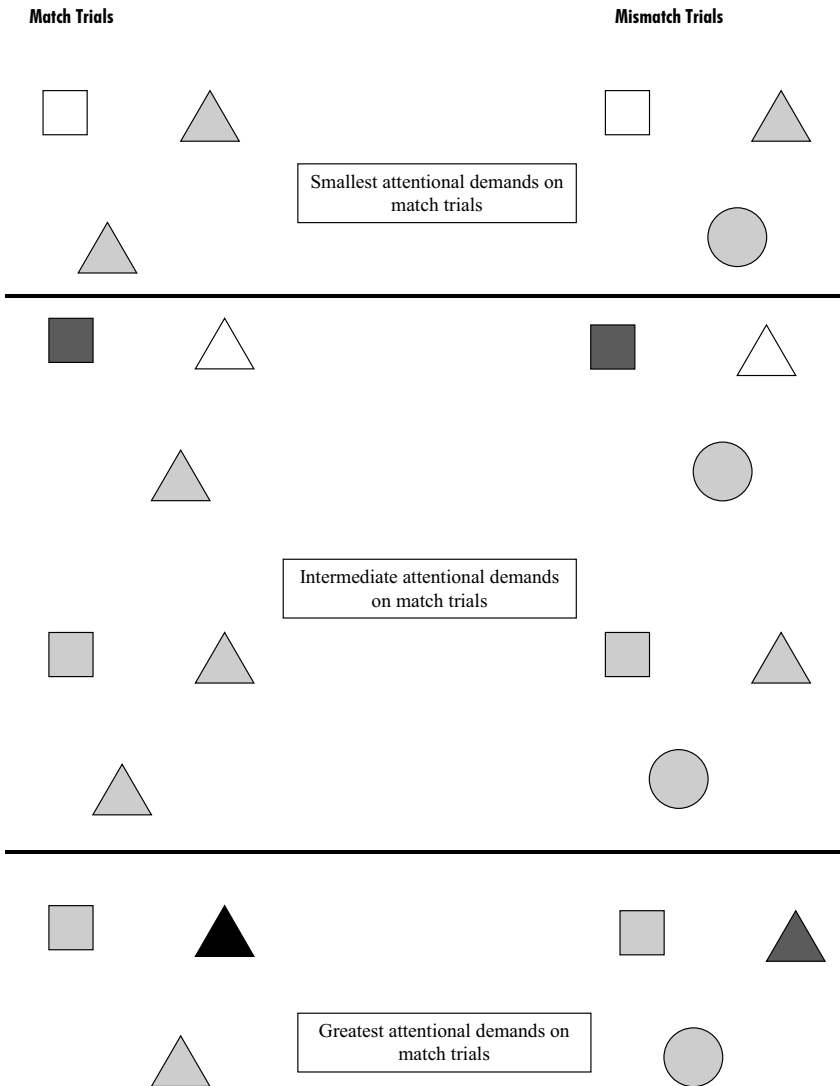


FIGURE 2 Sample match and mismatch trials for the selective attention task.

matched the target in color (facilitating the decision that the probe matched the target), and the different-form probe also matched the target in color (hindering the ability to identify that probe as not matching the target). These trials made up 33.3% of all match trials. The fourth category required the largest degree of selective attention. In this category, the same-form probe was different in color than the target (hindering the recognition of the match in form), and the different-form probe matched the target in color (hindering the ability to identify that probe as not matching the target). These trials were 16.7% of all match trials. When items were different colors, they were always from a different color category (e.g. green, blue, purple) and were never variants within a category (e.g., sky blue, azure).

Mismatch trials were similarly constructed with regard to variations in color (see Figure 2). In sum, the proportion of both match and mismatch trials were such that 33.3% of all trials were composed of items that were all the same color (e.g., all midnight blue), 33.3% were composed of trials in which two items were the same color and the third item was a different color (e.g., two midnight blue and one cherry red), and 33.3% were composed of trials in which all three items were different colors (e.g., one midnight blue, one cherry red, and one lime green).

*Procedure.* Children received 24 practice trials and 144 test trials that were equally divided across six blocks (two blocks of trials in which all the items were the same color, two blocks of trials in which two items were the same color and the third was a different color, and two blocks of trials in which each item was a unique color). On each trial the stimulus display appeared for 3,000 msec. Children indicated their decision by pressing the space bar if one of the probes was the same shape as the target and pressed no key if all shapes were different (go–no-go response). The hand used to respond was counterbalanced across blocks. This task required approximately 30 min for completion.

## Equipment

Both tasks were presented on a Macintosh IIci computer with an Apple Color monitor. SuperLab software 1.55 was used to program the experiment. Children were seated in a comfortable chair 23.9 in. from the computer monitor with their heads in a chinrest to restrict head movements. They were provided with as many breaks as needed during the 1.25-hr test session.

## RESULTS

### Interhemispheric Task

*RT.* We performed repeated measures analysis of variance (ANOVA) on median RTs for match trials with *group* as the between-subject factor (younger = less

than 10.5 years old; older = more than 10.5 years old). The within-subjects factors were *task* (physical identity, name identity), *trial type* (within hemisphere, across hemisphere), and *visual field of the matching probe* (LVF, RVF). We included this last factor in our analysis (visual field of the matching probe) because our prior work has suggested that the match decision is made by the hemisphere contralateral to this probe on both within-hemisphere and across-hemisphere trials (for a longer explanation, see Banich, 1995).

This analysis revealed a main effect of the group factor,  $F(1, 22) = 4.48, p < .05$ , reflecting the fact that younger children responded more slowly (631 msec) than older children did (506 msec). Because we did not wish our interpretation of the data to be confounded by this main effect, we transformed the data so that the across-hemisphere advantage was calculated as a percentage of mean RT [(average RT<sub>within hemisphere</sub> – average RT<sub>across hemisphere</sub>)/overall average RT]. A negative value indicates a within-hemisphere advantage.

We then performed an ANOVA using the between-subject factors of group and the within-subjects factors of task and visual field of the matching probe. The only significant finding in this analysis was a main effect of task,  $F(1, 22) = 13.14, p < .0025$ . This reflected a significant 12.47% across-hemisphere advantage for the name-identity task, as compared with the insignificant –1.7% (i.e., within-hemisphere) advantage for the physical-identity task. Thus, like the pattern observed in adults, across-hemisphere communication is more advantageous in children as computational complexity increases. The Group  $\times$  Task interaction did not reach conventional levels of significance,  $F(1, 22) = 2.91, p = .10$ , but results were in the direction of a larger across-hemisphere advantage for the younger children than for the older ones on the name-identity task (see Table 1). We obtained similar results when we used a normalized measure of performance (i.e., the difference in RT between within- and across-hemisphere trials divided by the standard deviation across all responses).

**Accuracy.** To obtain a measure of accuracy that was free from the response bias of individual children (e.g., responding impulsively or overly conservatively), we utilized  $d'$ . We performed repeated measures ANOVA on  $d'$ , again using the same between- and within-subjects factors. This analysis revealed a main effect of task,  $F(1, 22) = 8.19, p < .01$ , and a significant Group  $\times$  Task interaction,  $F(1, 22) =$

TABLE 1  
The Size of the Cross-Field Advantage as a Percentage of Mean Reaction Time

Task	Group	
	Younger Children	Older Children
Physical identity	–4.2%	0.0%
Name identity	16.8%	8.0%

7.61,  $p < .03$ . The younger children were significantly more accurate on the physical-identity task ( $d' = 3.34$ ) than on the name-identity task ( $d' = 2.52$ ),  $F(1, 22) = 15.79$ ,  $p < .001$ , whereas there was no significant difference in accuracy between the two tasks for the older children (physical-identity task,  $d' = 3.22$ ; name-identity task,  $d' = 3.21$ ). Finally, there was a significant Task  $\times$  Trial Type  $\times$  Visual Field of the Matching Probe interaction,  $F(1, 22) = 7.67$ ,  $p < .03$ . Decomposition of this interaction revealed that although there was a significant Task  $\times$  Trial Type interaction for both visual fields, LVF:  $F(1, 22) = 4.12$ ,  $p < .05$ ; RVF:  $F(1, 22) = 7.40$ ,  $p < .03$ , only the pattern for the RVF mimicked that observed previously in adults. When the matching probe was in the RVF, there was neither a within-hemisphere nor an across-hemisphere advantage for the physical-identity task, whereas a significant across-hemisphere advantage was observed for the name-identity task,  $F(1, 22) = 4.30$ ,  $p < .05$ . In contrast, when the matching probe was in the LVF, there was an unexpected across-hemisphere advantage for the physical-identity task,  $F(1, 22) = 5.44$ ,  $p < .05$ , and there was neither a within- nor an across-hemisphere advantage for the name-identity task. This pattern may reflect a speed-accuracy trade-off for LVF trials for the physical-identity task.

### Selective Attention Task

*RT.* We performed a repeated measures ANOVA on median RT for match trials with the between-subject factor of group (younger, older) and the within-subjects factors of *color of same-form probe* (same as target, different than target) and *color of different-form probe* (same as target, different than target). This analysis revealed a main effect of color of same-form probe,  $F(1, 22) = 56.26$ ,  $p < .0001$ , because, not surprisingly, responses were made significantly more quickly when the same-form probe was the same color as the target (993 msec) as compared with a different color (1,152 msec). There was also a significant Color of Same-Form Probe  $\times$  Color of Different-Form Probe interaction,  $F(1, 22) = 6.30$ ,  $p < .025$ , which was modified by a marginally significant interaction of Group  $\times$  Color of Same-Form Probe  $\times$  Color of Different-Form Probe,  $F(1, 22) = 4.13$ ,  $p < .06$ . Tests on this three-way interaction indicated that it was entirely due to a Color of Same-Form Probe  $\times$  Color of Different-Form Probe interaction for the younger group,  $F(1, 22) = 10.32$ ,  $p < .005$ , because no effect existed for the older group ( $p > .7$ ; see Table 2). For the younger group, when the target and same-form probe were the same color, responses were faster when the different-form probe was the same color as the target (985 msec) rather than a different color (1,065 msec). Hence, responses were speeded when all the stimuli were the same color as compared to when two of the stimuli were one color and the third stimulus was a different color. When the same-form probe and target were different colors, responses were faster when the different-form probe and target were different colors (i.e., when all three stimuli were different colors; 1,137 msec) rather than the same color (1,226 msec).

TABLE 2  
Median Reaction Time in Milliseconds for the Selective Attention Task

<i>Same-Form Probe</i>	<i>Different-Form Probe</i>			
	<i>Younger Children</i>		<i>Older Children</i>	
	<i>Same Color</i>	<i>Different Color</i>	<i>Same Color</i>	<i>Different Color</i>
Same color	985	1,065	954	968
Different color	1,226	1,137	1,125	1,121

Once again, it appeared more difficult for the younger children to detect the matching probe when there was one distinctly colored stimulus.

**Accuracy.** An ANOVA on error rates (i.e., not detecting a match) was performed using the same between- and within-subjects factors as in the previous analysis. No significant results were obtained, although there was a trend for a main effect of Color of Same-Form Probe,  $F(1, 22) = 3.41, p < .08$ . This occurred because error rates tended to be lower when the matching probe was the same color as the target (1.2%) as compared to when the matching probe was a different color (3.7%).

### Correlational Analyses

We performed a number of correlational analyses to examine the relations between age, interhemispheric interaction, and attention. To determine whether the degree of interhemispheric interaction changes as a function of age, for each task we correlated age and each dependent measure,  $d'$  and RT. The size of the across-hemisphere advantage for  $d'$  ( $d'_{\text{across}} - d'_{\text{within}}$ ) and age were not correlated for either task. In contrast, the correlations between age and across-hemisphere advantage for RT were significant. For the physical-identity task, there was a significant positive correlation indicating that a younger age was associated with a larger within-hemisphere advantage,  $r(22) = .40, p < .05$  (see Figure 3). In contrast, for the name-identity task, there was a significant negative correlation indicating that a younger age was associated with a larger across-hemisphere advantage,  $r(22) = -.52, p < .01$  (see Figure 4). Hence, it appears from both these correlational analyses and the results of the ANOVA that younger age is associated with a greater differentiation between within- and across-hemisphere processing for the two tasks.

We examined the relation between age and attentional performance by correlating age with a measure of how much color interfered with making the decision based on form. Remember that in our trials the same-form probe (i.e., matching probe) could be either the same color as the target or different. We examined the correlations separately for each of these trial types. To obtain a measure of how

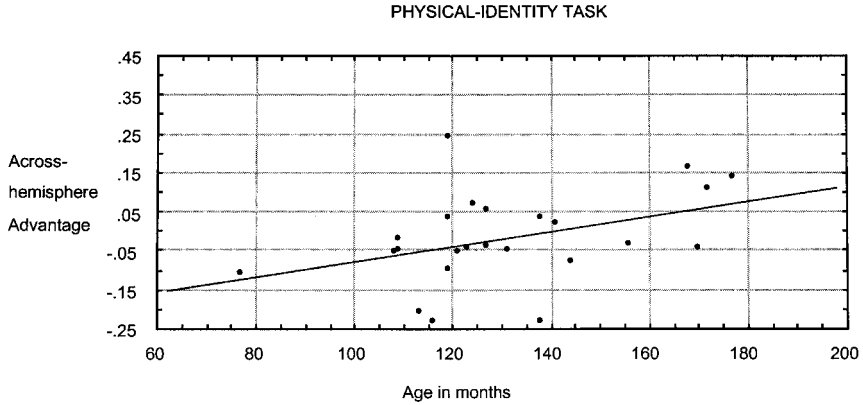


FIGURE 3 Correlation of age with the across-hemisphere advantage as a function of mean reaction time for the physical-identity task,  $r(22) = .40$ ,  $p < .05$ . A negative value indicates a within-hemisphere advantage.

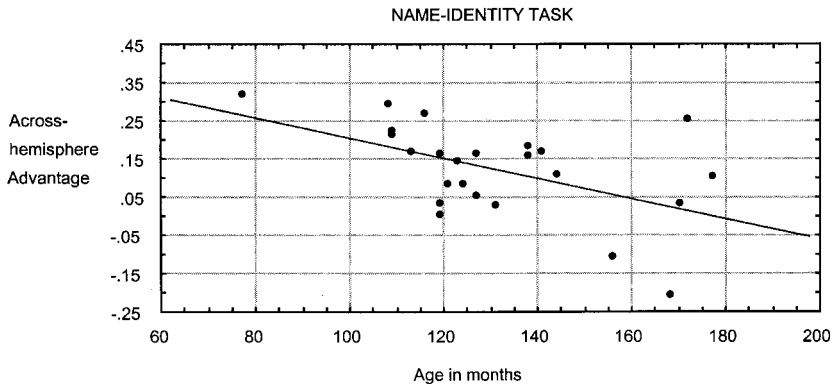


FIGURE 4 Correlation of age with the across-hemisphere advantage as a function of mean reaction time for the name-identity task,  $r(22) = -.52$ ,  $p < .01$ . A negative value indicates a within-hemisphere advantage.

much color caused interference, we calculated how much longer it took an individual to respond when the different-form probe was the same color as the target (and hence would be distracting) as compared to when it was the same color.

When the same-form probe was the same color as the target, there was no correlation between age and the amount of interference engendered by the color of the dif-



ferent-form probe. However, when the same-form probe was a different color than the target, the correlation was significant,  $r(22) = -.53, p < .01$ . This correlation indicates that the younger the child, the more he or she was slowed in the detection of the matching form when the mismatching probe was the same color as the target, as compared with a different color. This correlation appears to indicate that when there is competing information (i.e., matching form but mismatching color), younger children are slower to ignore the task-irrelevant attribute (i.e., color).

Finally, we examined the correlation between the across-hemisphere advantage (as a percentage of RT) for each task and the ability to selectively attend. As our measure of selective attention, we utilized the degree to which RT was slowed (i.e., the degree to which a child was distracted) when the color of the different-form probe was the same color as the target, as compared to when it was different. There were no significant correlations for the physical-identity task. For the name-identity task, however, we found a positive correlation,  $r(22) = .42, p < .05$ , for trials on which the same-form probe was a different color than the target. For these trials, we found that a larger across-hemisphere advantage on the name-identity task was associated with a greater degree of interference from the different-form probe. Hence, those children who had the most difficulty in selective attention had the largest across-hemisphere advantage. This may seem to suggest that children who invoke across-hemisphere processing on the name-identity task are those who are less adept at attentional functioning. Such a finding would seem to be at odds with the idea that interaction between the hemispheres aids in reducing the effect of distracting information. This effect, however, seems to be mediated mainly by age, because the partial correlation between the across-hemisphere advantage and the interference by color after partialing out the effect of age was only .20.

## DISCUSSION

The results of this experiment indicate that the relation between interhemispheric interaction and computational complexity in children is similar to that which we have previously observed in adults. As in adults, children appear to benefit from dividing processing across the hemispheres as computational complexity increases. This effect was reflected in the significant across-hemisphere advantage in RT for the more complex name-identity task and in the fact that there was neither a within- nor across-hemisphere advantage for the physical-identity task. This pattern was observed in both the younger group of children, aged 6 to 10.5 years, and the older group of children, aged 10.5 to 14 years. The accuracy data were only partially consistent, exhibiting a similar pattern (i.e., a greater across-hemisphere advantage for the name-identity than for the physical-identity task) for trials in which the matching probe was presented to the RVF but not the LVF. The reason for this discrepancy is not entirely clear. Overall, however, it appears that interaction between the

hemispheres is moderated by computational complexity by the time children reach grammar school.

Nonetheless, the correlational analysis provided evidence for some changes in interhemispheric processing between the ages of 6 and 14. We found that the younger the child, the larger the within-hemisphere advantage on the physical-identity task and the larger the across-hemisphere advantage on the name-identity task. These results suggest that, if anything, the pattern we observe in adults is exaggerated in younger children. It appears unlikely that this pattern reflects the functioning of an immature callosum when one considers that the younger the children, the larger the across-hemisphere advantage. If the callosum of younger children were less functional, we would have expected a diminution in the size of the across-hemisphere advantage. Rather, we take these results to be consistent with our hypothesis that across-hemisphere processing is more advantageous under computationally complex conditions. Because younger children are more likely to be taxed by the demands of the name-identity task than older children, across-hemisphere processing becomes particularly advantageous. In this respect, the data from this study converge with those of Reuter-Lorenz et al. (1999) and of Reuter-Lorenz and Stanczak (this issue), who found a greater across-hemisphere advantage at lower levels of computational complexity in older than younger adults. Hence, populations particularly challenged by computational complexity may invoke across-hemisphere processing as a mechanism to cope with increased computational demands.

With regard to selective attention, we obtained evidence from both the ANOVA and the correlational analyses that older children were better able to ignore the distracting information provided by color when a decision was to be based on a stimulus's form. Such a result is not particularly surprising. However, it does verify the validity of our measure of selective attention as sensitive to developmental changes. More specifically, both groups of children were faster to detect the match in form when the target and same-form probe were the same color, as compared with different colors. The older children, however, were less influenced by the color of the different-form probe. Hence, the older children were more able to ignore color information that falsely suggested that the items matched when in fact their forms were different.

Despite finding evidence for developmental changes in the nature of interhemispheric interaction as a function of task complexity and the ability to selectively attend, we did not obtain strong evidence that these two processes covaried. Rather, the relation between these two variables appeared to be mediated by joint correlations with age. The lack of a relation in our data, however, does not preclude its existence, because such a relation could have been swamped by the effects of age. It is possible that the utility of interhemispheric interaction as a function of task complexity may predict individual differences in selective attention within a group of children who are all of more similar age. This issue must await future investigation.

In sum, our data indicate that by the grammar school years, interaction between the cerebral hemispheres acts a means to deal with computational complexity, as has previously been observed in adults. However, our correlation data provide evidence that the effects of interhemispheric interaction may not be entirely static during this time. Rather, it appeared that the younger the child, the more likely it is that interhemispheric interaction is beneficial to task performance. We suspect that this association occurs because younger children have less capacity within a single hemisphere to deal with computational complexity, making interaction more beneficial to performance. The implication of this finding, such as whether it influences the developmental course of mental functions such as attention, remains an open issue.

### ACKNOWLEDGMENTS

Portions of this research project were supported by Grant R01 MH 54217 from the National Institute of Mental Health to Marie T. Banich.

We thank Laura Glaser for help in testing the children. We also thank Desiree White and Warren S. Brown for helpful comments on the article.

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