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Developmental Changes in Processing Speed: Influence of Accelerated Education for Gifted Children

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Abstract

There are two major hypotheses concerning the developmental trends of processing speeds. These hypotheses explore both local and global trends. The study presented here investigates the effects of people's different knowledge on the speed with which they are able to process information. The participants in this study are gifted children aged 9, 11, and 13 years. A total of 94 of the participants were members of gifted programs, whereas the other 93 children received standard education. They were required to finish two information-processing tasks: a Choice Reaction Time task and an Abstract Matching task. The results show that the reaction time of gifted children who received accelerated education in gifted programs was significantly faster than that of the children who received standard education at every age. These results seem to imply that the educational atmosphere in which a child is placed plays a significant role in the development of gifted children's speed of information processing.

Putting the Research to Use

This study serves to demonstrate that experience and knowledge may influence the development of information processing speed. It appears that specialized education for gifted children can actually accelerate development, suggesting that selection of educational system is of particular significance, especially for gifted children. Gifted children can study more quickly than average children because they have a higher speed of information processing. The efficacy of their study results in greater transmission of knowledge, and this in turn accelerates gifted children's information processing speed. Accelerated education can not only satisfy the cognitive need of gifted children but also serve to enhance their cognitive development. Teachers and parents have to recognize that education is very important to children's development and address the importance of experience in gifted children's learning. The results of the present study also suggest a need for a special education system designed for gifted children, which can be viewed as a great investment in the future.

Keywords

gifted children, speed of information processing (SIP), accelerated education, development

The measurement for the speed at which the children are able to process information (SIP) provides the index of the speed and efficiency with which the central nervous system may process information (Fink & Neubauer, 2001). Reductionists have said that the SIP reflects some fundamental characteristic of the brain, such as neuronal transmission speed (Luciano et al., 2005). Reaction time (RT) is the measure used to show the speed at which perceptual information is processed. This requires the participant to make multiple comparisons or memory search. Measurements of RT have been used extensively in developmental research, especially in the research of cognitive processes (Brewer & Smith, 1989). A systematic increase in processing speed has been proposed to underlie cognitive development (Ferguson & Bowey, 2005; Hale, 1990; Kail, 1991b, 1992, 2000).

Developmental studies that have been done on SIP demonstrate that for many tasks RT decreases from childhood to early adulthood (Brewer & Smith, 1989; Demetriou, Mouyi, & Spanoudis, 2008; Wickens, 1974). These tasks range from simple and choice reaction time to more complex tasks such as mental rotation and verbal analogies. The studies show that, in general, the RTs of younger children are slower than that of older children, and the older children in turn perform slower than adults (Hale, 1990; Kail, 2000).

Research in this area indicates that a number of factors may aid in the improvement of the RT performance that is observed with increasing age (Brewer & Smith, 1989). These factors

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have been the focus of investigations on processing speed. A number of theories have been developed to explain the age-related change in processing speed. There are two main hypotheses concerning the developmental trends observed in processing speed. These hypotheses are termed *global* and *local* (Hale, 1990). Both hypotheses have received a great deal support from the considerable amount of research in this field over many years.

The Global Trend Hypothesis assumes that all information-processing components develop in concert, that is, at similar rates (Hale, 1990). According to this hypothesis, some central mechanism, which changes gradually with age, may limit the rate at which children are able to process information (Ferguson & Bowey, 2005; Kail, 1992).

The logic behind their research is as follows: If the speed of different processes is limited by a common global mechanism, then the same pattern of developmental change in processing speed is expected for these different processes. If, instead, the speed of each process reflects specific experiences or practice, then patterns of developmental change should vary across different processes. By this reasoning, Kail (1991a, 2000) found that on a wide range of motor, perceptual, and cognitive tasks, a common pattern of age differences emerged: 8- to 10-year-olds' processing speed was typically 5 to 6 standard deviation (*SD*) units below young adults' processing speed; 12- and 13-year-olds responded at a speed more than 1 full *SD* below the average processing speed of young adults. As the hypothesis predicts, processing speeds for such tasks as mental addition, mental rotation, memory search, and simple motor skills all change at a common rate that can be well described by an exponential function (Kail, 1988, 1991b).

In a meta-analysis, 72 studies on information-processing tasks were surveyed, from which Kail drew two conclusions. First, youths' RTs can be expressed as a multiple of adults' RTs across a wide range of conditions, indicating that some general factors are involved in age-related change in speeded performance. Second, speeded performance changes with age in a manner that can be described with an exponential function (Hale, Fry, & Jessie, 1993; Kail, 1991a).

The local trends hypothesis assumes that information processing components change with age, but different components develop at different rates (Hale, 1990). One general explanation of increased processing speed over time is about task-specific knowledge (Roth, 1983). Several lines of research have shown that differences in knowledge may result in the differences of processing speed (Brewer & Smith, 1989).

Some researchers concluded that typical adult superiority in processing speed was to some extent because of a difference in general knowledge. These studies indicated that various aspects of knowledge (domain-specific knowledge, familiarity with the stimuli) do affect the rate of processing. Adults are not only older than children but are also likely to have more knowledge about the stimuli. Consequently, researchers have argued that typical adult superiority in processing speed may often be a result of richer knowledge, rather than merely to a difference in age or maturity alone. It has been shown that the differences in processing speed between children and adults are reduced when children and adults are equally knowledgeable about the stimulus domain (Roth, 1983). This suggests that efficient processing associated knowledge underlie developmental changes in speed (Brewer & Smith, 1989).

Stokes and Bors's (2001) study shows that practicing a particular task results in a significant increase in performance accuracy. Anderson, Reid, and Nelson (2001) found that prior knowledge of a task is of an order of magnitude larger than maturational processes in inspection time for children.

Rabinowitz, Ornstein, Folds-Bennett, and Schneider (1994) think that the amount of research has mixed or confused the effects of age and knowledge. Their study was designed to explore age constraints on processing speed in a lexical decision task in the absence of the usual age–knowledge confound. Participants of different ages were presented with two lexical decision tasks, one in German (their native language) and one in English (their second language). These results suggest that knowledge is an important factor to consider, at least in this context (Rabinowitz et al., 1994).

Although many studies have found developmental changes in the speed of various processes, they have potentially confounded the subjects' age with their knowledge (Hale, 1990). How can one most accurately determine which hypothesis accounts for age-related differences in processing speed? The aim of the present research was to test these hypotheses by choosing subjects with different amount of knowledge. Gifted children constitute a special population. For such children, there is an accelerated education system in some schools in Beijing. In this system, gifted children spend only 4 years in primary school to complete their studies, which are typically completed in 6 years. These same students finish the normal 6 years of high school studies within 4 years. The programs for gifted children are not, however, used by the entire population of gifted children, as many still receive the standard schooling of the general population (Zha & Zhou, 1993).

By virtue of the accelerated education that they receive, gifted children in this system are typically more knowledgeable in a greater range of subjects than the gifted children who remain in the general student population. If knowledge plays a role in determining the processing rate, it would be expected that gifted children in the accelerated education would be superior to gifted children in normal education system. The Global Trend Hypothesis would be strongly supported if the two groups of gifted children respond at the same rate.

We revised Chi's (1977) research paradigm that was employed in memory recall tasks (see also Roth, 1983). Using the same rationale, the present study investigated the effects of age and knowledge differences on two tasks comparing the performance of each group of children across three age ranges.

Method

Participants

The participants, aged 9, 11, and 13 years, come from one primary school and one high school. The gifted education program mentioned previously has only been adopted in a few of Beijing's schools. Each school has only one gifted class with roughly 30 students. These gifted children are designated as such by means of multiple tests, including academic performance, creative thinking, and personality (Zha, 1994; Zhou & Zha, 1986). Because of limited educational resources, not every gifted child can receive accelerated education, and many gifted children just receive the normal education.

The gifted children who receive accelerated education comprise the gifted experimental group, whereas the normal education group came from the normal classes. Cattell's Culture Fair Test was administered to the two groups. Their raw scores on Cattell's Culture Fair Test are displayed in Table 1. The differences of the two groups' intellectual score, $F(1, 183) = 1.04$, $p > .05$, and their age, $F(1, 183) = 0.24$, $p > .05$, are not significant. Detailed participant descriptions are presented in Table 2.

Table 1. Cattell's Culture Fair Test Scores in Each Group

	9-Year-Olds	11-Year-Olds	13-Year-Olds
Accelerated	36.13 ± 2.54	40.44 ± 1.80	42.68 ± 1.66
Normal	35.29 ± 1.98	40.23 ± 1.14	42.37 ± 1.13

Table 2. Age Distributions and Number of Children in Each Group

	9-Year-Olds	11-Year-Olds	13-Year-Olds
Accelerated	8.91 ± 0.24 (31)	11.07 ± 0.36 (32)	13.09 ± 0.31 (31)
Normal	8.83 ± 0.23 (31)	11.00 ± 0.36 (30)	12.98 ± 0.54 (30)

Note: Figures in parentheses denote the number of participants.

Apparatus

The experiment was performed on a Pentium-PC, and all of the tasks were programmed with E-Prime software. The computer records related data automatically.

Tasks

Choice Reaction Time (CRT) task. There were three kinds of materials in this task: digits, English letters, and simple Chinese characters. There were two rows of stimulus on the screen, the first row consisted of one digit (or letter or Chinese character), and the second row consisted of four digits (or letters or Chinese characters; see Figure 1). The participants were required to judge whether the stimuli in the first row exist in the second row by pressing "yes" or "no" keys. The probability of "yes" or "no" was equal. There were 8 practice trials and 64 experimental trials.

Abstract Matching (AM) task. This task was a modification of Hale's (1990) task. There was a big frame shown on the screen during experiment. The stimuli consisted of three arrangements of three different displays of two, three, or four simple shapes (circle, triangle, and cross) presented in one of three orientations (horizontal, vertical, and diagonal). There were three arrangements in the frame: one was on the left, the second was on the right, and the third was at the bottom, as shown in Figure 2. These patterns could vary along three dimensions: shape, number, and orientation of the patterns. Participants were required to decide whether the left pattern or the right pattern was most like the bottom one by pressing keys. There were two levels of task complexity based on the number of irrelevant dimensions held constant across all three patterns: at Level 1, one of the dimensions held constant; at Level 2, none of the dimensions held constant. There were 10 practice trials and 36 experimental trials.

Procedure

The tasks were administered individually by separate testers. Instructions were given at the beginning of each task. Children were encouraged to keep their index fingers placed on the corresponding keys throughout testing. After every 18 or 20 trials, children could have a short break. Each child was then given feedback that generally told them that their performance was excellent and encouraged them to keep trying. During testing, the researcher conducting the experiment monitored the performance of each child, ensuring that they had not forgotten the stimulus–key mapping. Total testing time, including instructions and practice, varied between 20 and 25 minutes.

Results

The Reaction Time and Accuracy of the CRT Task

Descriptive statistics of the CRT task are shown in Table 3.

Reaction time. A multivariate analysis of variance (MANOVA) showed that the interaction of age and education group was insignificant, $F(2, 179) = 0.78$, $p > .05$, $\eta^2 = 0.9\%$. The main effect of age was significant, $F(2, 179) = 79.94$, $p < .01$, $\eta^2 = 47.2\%$. The main effect of education was significant, $F(1, 179) = 43.90$, $p < .01$, $\eta^2 = 19.7\%$, and the main effect of material was also significant, $F(2, 358) = 50.53$, $p < .01$, $\eta^2 = 22.0\%$. The interaction of material and age was significant, $F(4, 358) = 4.24$, $p < .01$, $\eta^2 = 4.5\%$. The interaction of material and education was insignificant, $F(2, 358) = 0.15$, $p > .05$, $\eta^2 = 0.1\%$. The interaction of material, age, and education was insignificant, $F(4, 358) = 0.58$, $p > .05$, $\eta^2 = 0.6\%$.

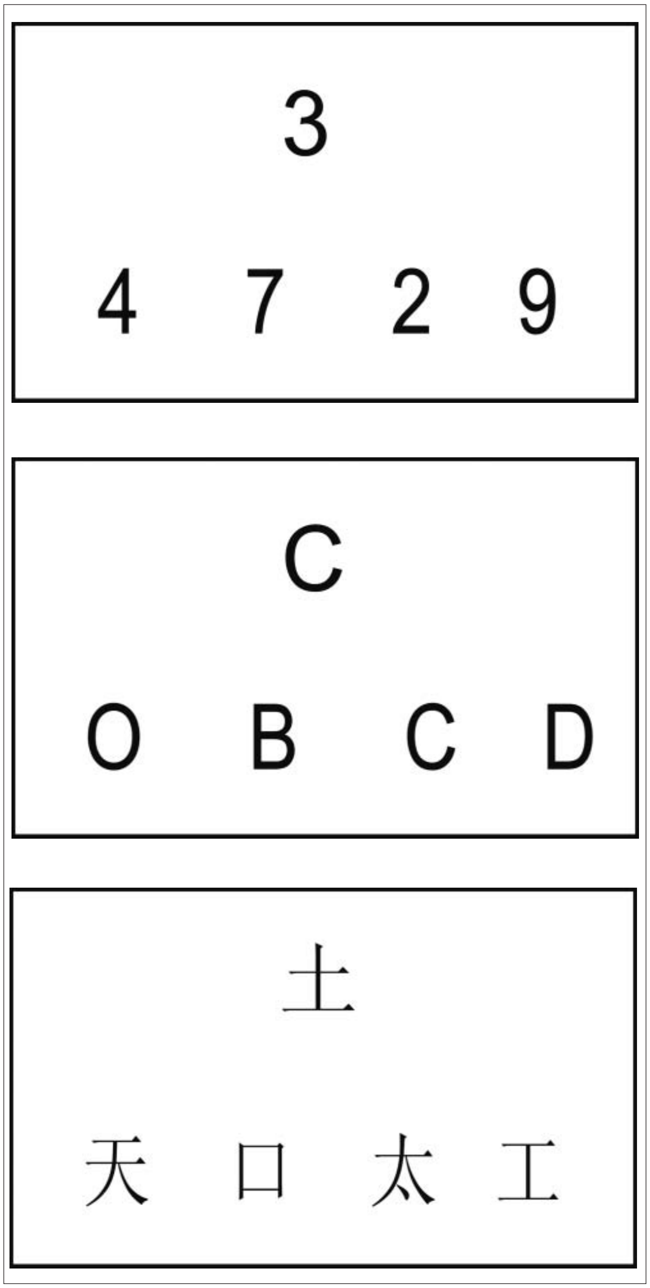

Figure 1. Three kinds of material in the Choice Reaction Time task

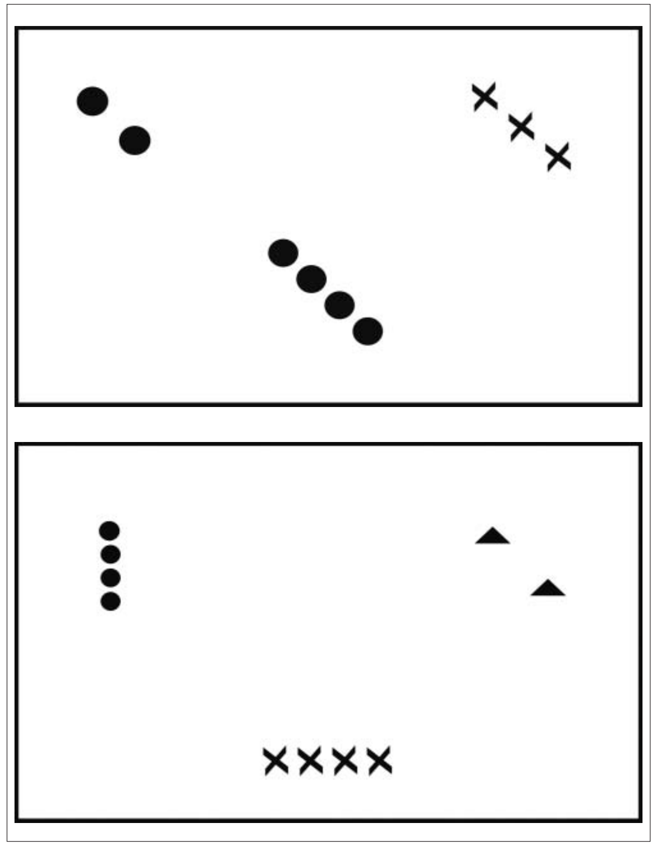

Figure 2. Two levels of task complexity in the Abstract Matching task

The post hoc test showed that the choice reaction time decreased gradually as children's age increased and there were significant differences between ages 9 and 11, 9 and 13, and between 11 and 13 years, *p*s < .05. Furthermore, the children in accelerated education did respond more quickly than children in normal education.

Accuracy. The MANOVA showed that the interaction of age and the education group was insignificant, $F(2, 179) = 2.35$, $p > .05$, $\eta^2 = 2.6\%$. The main effect of age was significant, $F(2, 179) = 29.21$, $p < .01$, $\eta^2 = 24.6\%$; the main effect of education was insignificant, $F(1, 179) = 0.82$, $p > .05$, $\eta^2 = 0.5\%$; the main effect of material was also significant, $F(2, 358) = 12.12$, $p < .01$, $\eta^2 = 6.3\%$. The interaction of material and age was insignificant, $F(4, 358) = 0.186$, $p > .05$, $\eta^2 = 0.2\%$. The interaction of material and education was insignificant, $F(2, 358) = 0.01$, $p > .05$, $\eta^2 = 0.0\%$. The interaction of material, age, and education was insignificant, $F(4, 358) = 0.91$, $p > .05$, $\eta^2 = 0.7\%$. The post hoc test showed that the children's accuracy increased gradually as their age increased, and there were significant differences between 9- and 11-year-olds, 9 and 13 years old children in accelerated and normal education group, *p*s < .05.

The Reaction Time and Accuracy of the AM task

Table 4 displays the descriptive statistic of the AM task.

Reaction time. The MANOVA showed the interaction of age and education group was insignificant, $F(2, 179) = 1.40$, $p > .05$, $\eta^2 = 1.5\%$. The main effect of age was significant, $F(2, 179) = 30.25$, $p < .01$, $\eta^2 = 25.3\%$; the main effect of education was significant, $F(1, 179) = 28.00$, $p < .01$, $\eta^2 = 13.5\%$; the main effect of task level was also significant, $F(1, 179) = 274.42$,

Table 3. The Reaction Time and Accuracy of the Choice Reaction Time Task

		Digit		Letter		Chinese Character	
		Reaction Time	Accuracy	Reaction Time	Accuracy	Reaction Time	Accuracy
9-Year-Olds	Accelerated	1,024 (190)	0.85 (0.11)	1,061 (193)	0.83 (0.10)	1,060 (202)	0.84 (0.11)
	Normal	1,185 (152)	0.83 (0.13)	1,211 (158)	0.80 (0.10)	1,217 (162)	0.81 (0.13)
11-Year-Olds	Accelerated	903(126)	0.94 (0.05)	926 (122)	0.90 (0.04)	958 (115)	0.92 (0.04)
	Normal	1,037 (136)	0.91 (0.08)	1,085 (123)	0.89 (0.07)	1,109 (129)	0.89 (0.08)
13-Year-Olds	Accelerated	722 (85)	0.93 (0.04)	754 (96)	0.91 (0.04)	820 (135)	0.91 (0.06)
	Normal	825 (144)	0.94 (0.05)	859 (169)	0.92 (0.05)	907 (131)	0.93 (0.05)

Note: All times are in milliseconds. Figures in parentheses denote standard deviations.

Table 4. The Reaction Time and Accuracy of the Abstract Matching Task

		Level 1		Level 2	
		Reaction Time	Accuracy	Reaction Time	Accuracy
9-Year-Olds	Accelerated	1,751 (406)	0.93 (0.10)	2,243 (376)	0.92 (0.10)
	Normal	2,055 (506)	0.92 (0.08)	2,597 (158)	0.91 (0.11)
11- Year-Olds	Accelerated	1,595 (313)	0.97 (0.05)	1,957 (331)	0.98 (0.04)
	Normal	1,793 (393)	0.95 (0.08)	2,228 (484)	0.93 (0.12)
13- Year-Olds	Accelerated	1,139 (195)	0.94 (0.11)	1,394 (327)	0.90 (0.15)
	Normal	1,579 (356)	0.97 (0.05)	1,969 (351)	0.98 (0.04)

Note: All times are in milliseconds. Figures in parentheses denote standard deviations.

$p < .01$, $\eta^2 = 60.5\%$. The interaction of task level and age was significant, $F(2, 179) = 5.15$, $p < .01$, $\eta^2 = 5.4\%$. The interaction of task level and education was insignificant, $F(2, 179) = 2.99$, $p > .05$, $\eta^2 = 1.6\%$. The interaction of task level, age, and education was insignificant, $F(2, 179) = 0.26$, $p > .05$, $\eta^2 = 0.3\%$. The AM reaction time of children decreased gradually as their age increased. Children in accelerated education outperformed children in normal education by shorter RTs.

Accuracy. The MANOVA showed that the interaction of age and education was significant, $F(2, 179) = 4.90$, $p < .01$, $\eta^2 = 1.5\%$, and the main effect of age was significant, $F(2, 179) = 3.33$, $p < .05$, $\eta^2 = 3.6\%$; the main effect of education was insignificant, $F(1, 179) = 0.01$, $p > .05$, $\eta^2 = 0.0\%$; the main effect of task level was significant, $F(1, 179) = 4.09$, $p < .05$, $\eta^2 = 2.2\%$. The interaction of task level and age was insignificant, $F(2, 179) = 0.30$, $p > .05$, $\eta^2 = 0.3\%$. The interaction of task level and education was not significant, $F(2, 179) = 0.31$, $p > .05$, $\eta^2 = 0.2\%$. The interaction of task level, age, and education was significant, $F(2, 179) = 4.73$, $p < .05$, $\eta^2 = 5.0\%$. The accuracy of the children in both accelerated and normal education groups increased gradually as their age increased. Eleven-year-old gifted children in accelerated education performed more accurately than children in normal education, whereas 13-year-old gifted children in normal education performed more accurately than children in accelerated education. This pattern was more apparent at the task complexity of Level 2.

Discussion

The rationale of SIP tasks is that because these tasks are so easy they leave no room for intelligent strategic variations. Therefore, differences in performance can only be attributed to differences in the speed with which stimuli are processed and decisions are made (Rammsayer & Stahl, 2007). CRT is a simple perceptual judgment task that is used to test perceptual speed. AM is a more complex three-dimensional task and it concerns shape, number, and orientation.

The results of the analyses of the individual tasks from the current study are consistent with what the literature from previous studies has shown (Hale, 1990; Kail, 2000). The data showed two important things. On each task, 9-year-olds' scores were lower than those of 11-year-olds, which were in turn lower than those of 13-year-olds (Hale, 1990). Furthermore, the gifted children in accelerated education outperformed their similarly gifted peers who received normal education in the two tasks, as if they had a lower absolute RT. The current study has added important information to the performance characteristics of gifted children. Thirteen-year-old gifted children receiving normal education performed more accurately than children in accelerated education, while the reverse is true in 11-year-olds. If the results of RT are taken together, it is possible that they show that 13-year-old children in normal education are less impulsive.

In the current study, we examined two hypotheses concerning the nature of the development of information processing speed. How do our findings relate to each of the hypothesis described earlier? From one perspective, the Global Trend Hypothesis assumes that there is a central limiting processing mechanism that limits performance speed and that this mechanism changes with age. The time required to execute cognitive processes declines steadily during childhood and adolescence (Kail, 1991b). Children of the same age will have the same processing speed. In contrast, the Local Trends Hypothesis assumes that differences in knowledge may result in processing speed differences. The more knowledgeable children may have a higher speed. Overall, the results of the current study provide relatively weak support for the Local Trend Hypothesis. The researches supporting this hypothesis usually come from studies in the field of memory. The present study is a contribution to the more comprehensive and detailed understanding of this hypothesis and its application domain.

Cases such as these make it clear that all age differences in processing speed cannot be explained solely in terms of age difference. Instead, a complete account of age difference in processing speed will include both general and domain-specific components (Kail, 1991a). Stigler, Nusbaum, and Chalip (1988) had already challenged Kail's theory. They contend that skill transfer is a more plausible underlying mechanism. Gifted children in accelerated education have greater exposure to more stimuli, and it is possible that this kind of transfer helped them finish our tasks.

To pose this question more clearly, it is helpful to turn to research concerning cognitive differences in other special populations. Some studies have indicated that children with learning impairments process information at a slower rate than children without learning impairments (Weiler et al., 2000). We interpreted these results as suggesting that the underlying etiologies for the normal developmental change in processing speed, and those for the relative deficiencies in processing speed among children with learning disabilities, were different (Weiler, Forbes, Kirkwood, & Waber, 2003). The evidence reviewed above and our own results leave open the possibility that the mechanisms responsible for the normal developmental change and that of gifted children are different.

Although this study was limited in its sample to children in the age range of 9 to 13 years, the model used in this study provided a useful framework in which the nature of development of information processing speed could be explored. In general, the present paradigm appears to be an effective vehicle for clarifying the typical age–knowledge relation (Rabinowitz et al., 1994). However, many issues are still open. It would be worthwhile to extend this work with different age–knowledge–task combinations. Our findings are clearly relevant to considerations of age-related changes in information processing and for discussions of gifted education.

Any cognitive skills could be interrelated. Gifted children in accelerated education have more knowledge with stimuli, and it is possible that these kinds of stimuli transfer helped them in finishing our tasks. Gifted children in normal education are, however, not exposed to as many stimuli and are therefore, less knowledgeable with regards to such stimuli. Present research might imply that the knowledge gained at school and the educational environment play an important role in the development of gifted children's information processing speed. Schools and educators should provide more opportunities for children, as the more experience that a child has, the better their fundamental cognitive ability will be. Accelerated education may support the gifted students' optimal development and help them become more successful. This kind of education policy should be carried out on a nationwide scale. As additional research continues to clarify the nature of gifted children, theories about the development of information processing will be enhanced.

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