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Mind–culture interactions: How writing molds mental fluidity in early development

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ABSTRACT

This study investigated intellectual development in 4–7 years old Greek and Chinese children. They were examined on speeded performance, working memory, reasoning, and self-awareness tasks in order to investigate possible effects of learning the Chinese logographic system on possible differences in intellectual development between these ethnic groups. Speeded performance was examined with commonly familiar objects and tasks related to reading (i.e., Latin, Arabic, and Chinese characters). Chinese outperformed Greeks in (1) reading-related processing efficiency tasks but not in common objects (2) spatial but not verbal WM, (3) cognitive, and (4) the self-awareness tasks. Structural equation modeling showed that performance is organized in four systems (i.e., domain-specific problem solving, representational capacity, inference, and consciousness) integrated by *g*, in both ethnic groups. There were differences between the two ethnicities in the strength of relations between constructs, attributed to Chinese logographic experience. That is, the massive practice in visuo/spatial processing and memory seemed to provide an advantage in the communication between systems of the mind causing increased general cognitive fluidity, expressed in higher intellectual performance among the Chinese.

1. Introduction

Eastern nations in general and Chinese in particular outperform western nations by 5–10 points of IQ on standard intelligence tests (Lynn & Vanhanen, 2002). The nature, developmental origin, and causation of this difference are not clear yet. Explanations vary from primarily hereditary (Rushton & Jensen, 2005) to primarily environmental causes (Geary, Bow-Thomas, Lin, & Siegler, 1996; Geary, Salthouse, Chen, & Fan, 1996; Hedden et al., 2002; Stevenson et al., 1990). Interpretations of the nature of the difference also vary. Scholars stressing the genetic origin locate the differences in mechanisms underlying general intelligence (Jensen, 1998; Rushton & Jensen, 2005), such as the efficiency of information processing. Those stressing the environmental origins locate the difference in more specialized abilities, such as spatial reasoning, and the related culture practices which differentiate populations, such as the writing system (Demetriou et al., 2005). Finally, there is no clear answer as to when exactly the difference appears in development.

Answering these questions is theoretically and practically important. The architecture of the mind is still debated in the cognitive sciences. Therefore, accurately mapping possible differences in the organization and inter-relations of cognitive processes and their rate of development and explaining their origin (e.g., by specifying systematic differences in cognitively relevant experiences) would inform our theories about the organization and development of the human mind. Explaining the differences might inform educational interventions for the sake of empowering and consolidating

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cognitive functioning and development. The present study aimed to generate evidence relevant to these issues.

1.1. The architecture and development of the mind

Research and theory in psychometric (Carroll, 1993; Demetriou, 2002; Hunt, 2011; Jensen, 1998), cognitive (Hunt, 2002), and developmental psychology (Case, Demetriou, Platsidou, & Kazi, 2001; Demetriou, Christou, Spanoudis, & Platsidou, 2002; Demetriou, Mouyi, & Spanoudis, 2008, 2010; Demetriou, Spanoudis, & Mouyi, 2011) suggest that a tentative model of the human mind might include four types of systems which carry out different tasks during real time problem solving. The systems are as follows:

1.2. Specialized structural systems (SSS)

SSS involve mental processes that specialize in the representation and processing of different types of relations in the environment. The categorical (dealing with similarity–difference relations), the quantitative (dealing with quantitative variations and relations), the spatial (dealing with orientation in space and the imaginal–iconic representation of the environment), the causal (dealing with causal interactions between entities in the world), and the social SSS (dealing with other persons) emerge as distinct domains in factor analytic studies (see Case et al., 2001; Demetriou, Efklides, & Platsidou, 1993; Demetriou & Kazi, 2001; Demetriou et al., 2010, 2011; Shayer, Demetriou, & Pervez, 1988). Each is associated with distinct mental operations, operating soon after birth, which reflect differences in the relations between entities in the respective domains (e.g., classification, counting, mental rotation, hypothesis testing, theory of mind, for the five domains above, respectively (see empirical substantiation in Carey, 2009; Demetriou et al., 2010, 2011). With development, children can deal with concepts and problems of increasing complexity, abstraction, and flexibility in each of the SSS. It is noted that for the present purposes only the first three of these SSS were involved. It is recognized that there may be other ways to partition the mind into domains (e.g., Carey, 1985, 2009; Carroll, 1993). However, some domains (i.e., categorical, quantitative, and spatial reasoning) were identified by different traditions of research but it is beyond the present purposes to delve into this discussion (see Demetriou et al., 2010, 2011).

1.2.1. The representational capacity system

Representational capacity is the work-space of the mind where information is processed and represented. It is defined as the maximum amount of representations (e.g., mental images, words, or numbers) and mental operations (e.g., mental rotation, grammatical rules, or arithmetic operations) that the mind can efficiently activate simultaneously. Mental functioning at any moment occurs under the constraints of the available representational capacity (Baddeley, 1990; Cowan, 2010; Engel de Abreu, Conway, & Gathercole, 2010).

Representational capacity involves (i) modality-specific components, such as visual or acoustic and (ii) an executive component that ensures that mental processing serves the present goal (Baddeley, 1990). In most nations with formalized educational systems, preschoolers tend to be able to represent 1–2, primary school children 3–4, and adolescents and adults 5–7 chunks of information (Case, 1985; Demetriou et al., 2002, 2008; Halford, Wilson, & Phillips, 1998; Pascual-Leone, 1970).

The *Inference System* involves processes enabling the transfer of meaning from one representation to another (Demetriou et al., 2010, 2011). Inductive, analogical, and deductive reasoning are the main types of inference. Preschool children tend to be able to draw inductive and analogical inferences based on perceptual similarity between objects or relations. Also, at this age, propositions may be distinguished from each other and conclusions can be drawn, if organized as permission rules expressing modus ponens arguments (i.e., "If you do X, then you can do Y"). Later, at 6–7 years of age, conjunctive and disjunctive relations may be deduced if they involve familiar content (e.g., "if there is a either a cow or a goat then there is a pear; there is a cow; therefore there is a pear").

The *Consciousness System* involves processes ensuring (i) awareness of the current goal and, under some conditions, of the processes activated, (ii) evaluation of ongoing action relative to the goal, and (iii) control which ensures inhibition of unwanted actions and regulation of mental or overt action to goals (Demetriou, 2000; Gibson & Pick, 2003; Zelazo, Qu, & Müller, 2005; Zelazo et al., 2003). The executive processes in working memory derive from these processes.

All aspects of consciousness develop systematically from birth to maturity. In concern to the processes related to this study, preschoolers appear to be aware that thinking is internal mental activity referring to objects or events (Flavell, Green, & Flavell, 1995). However, 3- to 5-year-olds tend to judge underlying mental processes based on the perceptual similarity of the objects involved rather on what is going on in the thinker's head. At the age of 6 years children may recognize that pairs of tasks belonging to a different domain require different mental processes. At the age of 7–8 years children eventually may recognize mental operations as such, even when applied on different objects (Demetriou & Kazi, 2006).

Cognitive change results from the interaction of the various systems and ongoing learning experiences provided by the environment, formally or informally (Ceci, 1991). Increases in representational capacity enable the construction of increasingly more complex concepts. Changes in self-awareness and self-regulation result in better management of representational resources and in the reconstruction of representations into new and more inclusive representations. In turn, these reconstructions facilitate inference and problem solving in different domains (Demetriou et al., 2011). These changes are expressed in general intelligence or *g* itself. In the present context, *g* is defined in terms of the efficiency of activation and interaction between cognitive processes (indexed by speed), their volume (indexed by working memory), their directedness according to a current goal (indexed by executive control), and inferential power (indexed by reasoning and problem solving, which stands for psychometric fluid intelligence or *gf*). That is, changes in the quality of concepts or problems that *g* can master reflect increasing efficiency and flexibility in the interaction and communication between the various systems of the mind rather than a particular process or capacity (Demetriou et al., 2011; Van Der Maas et al., 2006). Increases in speed of processing reflect the improvement in communication between the systems and levels of the mind (Case, 1985; Demetriou et al., 2002, 2008; Kail, 1991).

2. Cross-cultural comparisons of cognitive processes

Many studies compared logographic with alphabetic cultures on various measures of cognitive ability. Chinese were often found to outperform Caucasians in various aspects of reasoning. Li, Nuttall, and Zhao (1999) reported that Chinese outperformed American undergraduates on the Water Level Task, which taps spatial reasoning, although others did not find this difference (Geary, Salthouse, et al., 1996; Stevenson et al., 1985). Several studies found that Chinese outperformed American children from kindergarten through primary school in various aspects of mathematical reasoning, although they were matched on general intelligence (Geary, Bow-Thomas, et al., 1996; Geary, Salthouse, et al., 1996; Geary et al., 1997), suggesting that educational rather than biological factors are crucial.

Chinese outperformed Caucasian in phonological or language-based measures of short-term storage span in childhood and adolescence (Chen & Stevenson, 1988; Demetriou et al., 2005; Geary, Bow-Thomas, et al., 1996; Hedden et al., 2002; Stigler, Lee, & Stevenson, 1986). Also, Demetriou et al. (2005) found that Chinese extensively outperformed Greek children in visuo-spatial short-term storage from 8 through 16 years of age. However, differences disappeared when tasks involved executive processes (Chen & Stevenson, 1988; Chincotta & Underwood, 1997; Demetriou et al., 2005; Hedden et al., 2002; Stigler et al., 1986). Thus, cross-linguistic differences in word digit span were ascribed to differences among languages in word length and ensuing differences in articulatory time and subvocal rehearsal time of digit names (Chincotta & Underwood, 1997), rather than in the executive processes underlying storage and retrieval. Likewise, any differences in spatial working memory were ascribed to differences in the facility to use the visual storage rather than in executive processes as such.

Comparisons on measures of speed of processing are particularly interesting, because they are supposed to reflect intellectual efficiency as such (Jensen, 1998; Kail, 1991, 2000). Generally, Chinese are faster than Caucasians on most measures at most ages (Geary, Salthouse, et al., 1996; Hedden et al., 2002; Jensen & Whang, 1994; Lynn & Vanhanen, 2002; Stevenson et al., 1985) and they were found to develop faster than American children (Kail, McBride-Chang, Ferrer, Cho, & Shu, in press). Demetriou et al. (2005) compared Greeks with Chinese, from 8 to 14 years of age, on measures of processing efficiency (speed and control of processing), working memory (phonological and visuo-spatial STS and executive processes), and reasoning. All processes were addressed through three domains of relations: verbal/propositional, quantitative, and visuo/spatial. Structural equations modeling and rating scale analysis showed that the architecture and developmental patterning of the various processes are basically the same in the two ethnic groups. The Chinese clearly outperformed the Greeks in all tasks addressing visuo/spatial processing, from processing efficiency through working memory and reasoning, but neither in *g* nor in the verbal or the quantitative domain. This advantage of the Chinese was associated to the massive practice in visuo/spatial processing that is required to learn the Chinese logographic writing system.

No important differences were found in the overall organization of processes (Demetriou et al., 2005; Stevenson et al., 1985). However, there were differences between Greeks and Chinese in the strength of relations between different systems. Specifically, visual memory appeared autonomous of other memory processes among Chinese, resulting, in turn, to faster development in visuo-spatial cognition after the age of eight years (Demetriou et al., 2005).

2.1. Writing systems and the mind

Writing systems differ in their cognitive demands and these differences may cause differences in cognitive and brain functioning and development (Cole & Pickering, 2010; Kolinsky, Morais, Content, & Cary, 1987; Mann, 1985; McBride-Chang et al., 2011; Tan et al., 2001). For example, in alphabetic systems symbols represent sounds, writing is linear (left to right), and reading words is dominated by phonological cognitive processes. In contrast, in Chinese the characters are the basic writing unit. Each is made of a number of strokes packed into a rectangular-shape space that represent meaningful morphemes in the spoken language. Writing in Chinese is two-dimensional and holistic (both up and down as well as left to right) (Li et al., 1999; Tan et al., 2001). An extra source of complexity comes from the fact that Chinese in not a fully pictographic system. In fact, Chinese is morphosyllabic, because it includes a semantic radical cueing the literal or metaphorical meaning of the character and a phonetic radical cueing pronunciation (see Cole & Pickering, 2010; Lee, Tsai, Huang, Hung, & Tzeng, 2006). This necessitates both understanding of the formal and functional constraints of character construction and the semantic and phonological aspects of the characters (Chan & Nunes, 1998). An additional source of difficulty in Chinese is that orthographically similar characters may be pronounced differently and orthographically different simple characters may have similar pronunciation (Tavassoli, 2002; Zhou & Marslen-Wilson, 1999). Despite this complexity, Chinese children learn at least 4000 different characters by the end of primary school; mature reader may visually distinguish and memorize more than 7000 logographs representing one syllable morphemes (Tavassoli, 2002).

In conclusion, the high visual complexity and visual differentiation of Chinese together with its low phonological differentiation impose a high demand on visual attention, perceptual analysis, visual working memory, and semantic integration of information in working memory and long-term memory (Chen & Juola, 1982; Tavassoli, 2002; Wang, Koda, & Perfetti, 2003). In line with this interpretation, some studies suggest that visuo-spatial working memory is a better predictor than phonological awareness of learning to read in Chinese (Cole & Pickering, 2010; Leong, Tan, Cheng, & Hau, 2005; Wang & Geva, 2003; Wang et al., 2003). European languages depend more on verbal rather than on visual short-term memory (Smythe, Everatt, Gyarmathy, Ho, & Groeger, 2003). Brain research lends support to these claims. Specifically, functional magnetic resonance imaging (fMRI) of brain activation when reading Chinese logographs shows that reading Chinese activates areas that are involved in intensive visual-spatial analysis and episodic integration of information which are not activated when reading English (Tan et al., 2001).

2.2. Aims and predictions of the study

This study was designed to examine possible organizational and developmental differences between Greek and Chinese children early in age and specify if these differences may be related to differences in the writing systems used in the two countries. This would contribute to the resolution of the debate noted above about the nature and origin of individual differences in intelligence, because it would show how differences in an important human invention, writing, may be transformed into differences in intellectual possibilities. It is also important to trace when in age these differences appear, if at all. To our knowledge, so far no study has looked into these differences in the early preschool years.

In sake of these aims, we developed the following tests: (a) Processing efficiency tasks varying in complexity (i.e., speeded stimulus recognition with and without interference from other stimuli and speeded reaction choice). They were (i) tasks relevant to the writing systems of each culture, i.e., letters and ideograms, and (ii) tasks common to both countries, i.e., shapes, numbers and objects. (b) Phonological and spatial working memory. (c) Quantitative and spatial problem solving. (d) Inferential processes, i.e., inductive and deductive reasoning. (e) Self-awareness about cognitive processes. These tests were addressed to 4- to 7-year-old children.

Admittedly, the precise matching of children across the two cultures in their previous exposure to reading beyond total time in formal education was not possible. It is noted, however, that all children started primary school education at the same age and they attended preschool education. Moreover, the precise matching of parents in education and income was not possible due to the vast differences between the two counties in socio-political organization. However, to ensure similarity between participants in the two countries in as far as this was possible, we opted to examine children of parents with university education in both countries. With these reservations present, we hope that the study can uncover any possible differential influences of reading differences between the two cultures. It is recognized, however, that the restriction of range in cognitive abilities that is associated with our option to examine children of educated parents in the two countries may limit the generalization of our findings to groups of the population with lower education.

Based on the literature reviewed and the design of the study, the following predictions could be tested.

1. *Performance differences*. Chinese might outperform Greeks on tasks requiring visuo-spatial processing, such as reading-relevant speeded performance, visuo-spatial working memory, and spatial reasoning, especially when they start learning to read and write, in primary school, that is, at the age of 6 and 7 years. It is an open question if there will be any differences in other aspects of reasoning at this early age, such as deductive reasoning or self-awareness, which were not investigated before. One might predict that any positive effects of writing on processing efficiency and working memory would need time to generalize to higher level processes, such as inference and self-awareness. In this case, an interaction between age and culture would have to be expected. It is of course noted that there may be other possible differences in the educational systems of the two countries which might interfere in subtle and not easily specified ways.
2. *Differences in the overall mental architecture*. No important differences in the architecture of the various processes were expected. Specifically, we expected that all processes examined (i.e., processing efficiency, working memory, problem solving, inferential processes, and self-awareness), will emerge as distinct factors, and all will be related to a higher-order general factor, *g*, in both cultures (see Fig. 6). This structure was found to be independent of age and culture (Demetriou et al., 2005; Shayer et al., 1988; Sternberg, 2004).
3. *Differences in the strength of relations between processes*. All component processes may be present in both ethnic groups but the strength of their relations might vary. This prediction was tested in a hierarchical model of structural relations where *g* was decomposed into the direct relations between processes (see Fig. 7). Specifically, processing efficiency, as a very general index of the quality of information processing (Coyle, Pillow, Snyder, & Kochunov, 2011; Jensen, 1998, 2006; Kail, 1991), would be related to all other processes; working memory, as an index of the overall representational constraints of the mind, would be related to reasoning and self-awareness (Case, 1985; Pascual-Leone, 1970); finally, self-awareness, as a regulatory function, would also relate to reasoning (Demetriou & Kazi, 2006; Demetriou et al., 2008, 2011, submitted for publication). It is commonly accepted in developmental psychology that the optimum ability associated with a given age may be differentially realized across processes and domains, depending upon complexity, familiarity, and social scaffolding. As a result, the covariation between processes increases as they approach this optimum, reflecting their increasing alignment to the optimum (Fischer & Bidell, 1998; Flavell, Miller, & Miller, 2001; Shayer et al., 1988). Based on these considerations, we expected that the relations between reading-related speeded performance, working memory, and reasoning tasks would be higher in the Chinese than in the Greek group, to reflect their better alignment to underlying optimum cognitive ability (Demetriou et al., 2005, 2008, 2011, submitted for publication).

3. Method

3.1. Participants

A total of 300 children, from four to seven years of age, were examined. There were 140 Greek and 160 Chinese children. Genders were about equally represented in each age group in both ethnic groups (see Table 1). All children lived in urban areas (Athens, Greece, and Changchun, Jilin Province, China) and came from parents with University education, for the reasons explained in the introduction. This sample is fully described in Table 1. There was no attrition of children selected for the study.

In both countries school curriculum is centrally controlled by the state and it is common for all children. Based on this curriculum, children do not directly learn to read and write during preschool but they are engaged in preparatory symbol recognition and writing-relevant activities, aiming to control

Table 1
Description of the sample.

Grade	Greek				Chinese			
	N	Mean age in months	StD	Range	N	Mean age in months	StD	Range
Kindergarten	38 (20, 18)	51.08	1.851	48–54	71 (36, 35)	49.49	1.620	47–57
Preschool	32 (16, 16)	62.06	1.999	60–66	27 (11, 16)	61.78	1.050	60–63
Grade 1	34 (14, 20)	76.35	2.087	73–80	31 (13, 18)	73.23	1.146	71–75
Grade 2	36 (15, 21)	89.53	2.184	86–93	31 (17, 14)	85.52	1.208	84–87

Note. The first and second numbers in parenthesis stand for females and males, respectively.

hand movements when writing. They are also involved in simple arithmetic activities, such as counting. Formally speaking, reading and writing starts at the first primary school grade in both countries. In both countries, children in urban areas go to kindergarten school at the age of 3 years and at preschool at 5 years. Children go to primary school in the first September following their sixth birthday in both countries. Admittedly, possible differences between the two countries in teacher education and in educational traditions at school and home preclude a complete equation of the two samples.

3.2. Tasks

3.2.1. Processing efficiency

Two broad types of speeded performance tasks were used. The first addressed *speed of processing* and it required the recognition of the target stimuli. The second addressed *control of processing* and it required selection of (i) the stimulus to be responded to or (ii) one response between others. These tasks were developed and addressed to children through the e-prime program for computer administered testing, which ensures that all relevant responses are automatically registered (Schneider, Eschman, & Zuccolotto, 2002). The e-prime SR-Box was used because it is child-friendly, as it has four easily discriminable buttons that can be programmed as response options as required. Accuracy of responses and reaction times on each trial were automatically stored.

3.2.1.1. Speed of processing measures. Three tasks addressed speed of processing:

(i) *Simon task*. Geometrical figures were randomly presented either to the left or the right side of the screen. Participants were instructed to press, as accurately and as fast as possible, the key on the SR-Box which corresponded to the side of the stimulus on the screen. Therefore, children responded to location rather than to any particular stimulus in this task. This task included 40 trials.

(ii) *Tasks involving domain-specific information*. Three sets of tasks involved information related to the quantitative (dots to be subitized), the categorical (objects to be recognized, such a glove or glass), and the spatial SSS (triangles or squares). Stimuli were presented in pairs to the left and the right side of the screen. They were (a) *identical* (i.e., two equal sets of dots, two identical objects or two identical geometrical figures), (b) *similar* (i.e., two different arrangements of the same number of dots, the same object in two different appearances, such as two visually different glasses, and the same geometrical figure oriented differently), or (c) *different* from each other. Participants were instructed to press the "same" key of the SR-Box when the configuration was either identical or similar and the "different" key when the configuration was different. Each set included 24 trials.

(iii) *Letters and ideograms*. Children judged the similarity of letters and ideograms, presented in pairs to the left and the right side of the screen. The pairs involved identical or different letters from the Latin (chosen to be similar with Greek letters) and the Arabic alphabet and Chinese ideograms. Pairs always included letters from the same alphabet; alphabets alternated randomly. This battery included 48 trials. To compare the two ethnic groups, all children responded to all tasks. Therefore, children in each ethnic group are more familiar to their national writing system rather than the national system of the other group and both are presumably less familiar with Arabic which is foreign to both of them.

3.2.1.2. Control of processing measures. To match the tasks above, the sub-batteries addressed to control of processing also involved quantitative (i.e., one vs. three dots), categorical (a car vs. a house), and spatial (a vertical vs. a horizontal line) information. The two stimuli of each battery were depicted on the keys of the SR-Box. Specifically, for the quantitative sub-battery, a miniature picture of the stimuli "one dot" and "three dots", that depicted the stimuli projected on the screen for this sub-battery, was placed on the buttons of the SR-Box. For the categorical sub-battery, the miniature pictures depicted the stimuli "car" and "house", and for the spatial sub-battery the stimuli "vertical" and "horizontal" line. Following Zelazo (Zelazo et al., 2003), there were two phases: *learning* and *control*. In the learning phase children were trained to respond to the item projected on the screen by choosing the respective key on the SR Box where this item was pictured. In the control phase children were instructed to choose the key *not* showing the item projected on the screen. Therefore, under these conditions, the test examines the ability of the child to inhibit the dominant tendency to choose the key *matching* the projected stimulus in favor of the weaker but relevant response "*shift* to the other one". Each battery included 24 trials in the matching phase and 24 trials in the control phase. Matching responses are considered to indicate speed of processing because they require stimulus recognition and a response primed by this stimulus. Shift responses are considered to indicate executive control, because they require response selection and execution despite the presence of a different stimulus prime (Zelazo et al., 2003). The three sub-batteries (quantitative, categorical and spatial) were administered separately. Thus, in each sub-battery the miniature pictures on the buttons of SR-Box matched the stimuli projected on the screen for the particular sub-battery.

In all tasks described above, reaction times of wrong choices and reaction times below a minimum (300 ms for the Simon task and 500 ms for the rest) and above a maximum value (5000 ms) were excluded from analysis. This is a common practice in this type of research aiming to ensure that the responses analyzed are relevant to the task (Jensen, 2006). Moreover, the 4-year-old children were screened for inclusion in the study on the basis of their performance on the Simon task. Specifically, only children succeeding on at least 70% of the trials on this task were retained for further testing (49% and 45% of the Greek and Chinese 4-year-old children). Screening was necessary for this age because pilot examinations showed that about 50% of this age group tended to respond randomly to speeded performance tasks. Therefore, this screening ensured that the youngest children included in the study were matched to the older children on their ability to respond reliably. There was no demographic bias in the origin of the children excluded under this criterion. No older child was dropped based on this criterion.

3.2.2. Short-term memory measures

3.2.2.1. Spatial memory (corsi). A 16×16 square layout was shown on screen; a cartoon figure stepped randomly in several of these squares and children recalled, in reverse order, where the cartoon figure stepped in. The task included seven levels (from one to seven cartoon appearances), with three items in each level.

3.2.2.2. Phonological memory. Two tasks were used: (a) words and (b) pseudowords. The first involved 34 familiar two-syllable words in each of the two languages. The second involved 34 two-syllable pseudowords, sounding like proper words in each language. It is noted that the Chinese pseudowords may be more meaningful than the Greek pseudowords, because they were constructed by inverting the order of two existing characters; these combinations may not always be nonsensical in Chinese (Tavassoli, 2002) as in the European languages. Children recalled the items in their presentation order. The tasks included five levels (from one to five words or pseudowords, respectively), with two items in each level.

Administration of all memory tasks stopped when participants failed to respond accurately to two items of the same level. The score on each of these three tasks equalled the higher level of difficulty attained on them.

3.2.3. Cognitive measures

Cognitive tests addressed the quantitative and the spatial SSS, and analogical and deductive reasoning.

3.2.3.1. Quantitative tasks. (a) Counting from 3 to 9 objects and (b) three arithmetic operations problems (i.e., finding the sum of 1+2, 2+3, and 7+4) addressed the quantitative SSS. The arithmetic operations problems were enacted by the experimenter, who placed as many cubes as required in a box. For example, in the first problem, she first placed 1 cube, then 2 more, and called the child to specify the number of cubes in the box. After each act the experiment covered the opening of the box to ensure that the objects in it could not be counted. For counting, the score was the maximum number of objects counted correctly. For arithmetic operations, one point was given for each correct answer.

3.2.3.2. Spatial task. This task involved three items requiring picture assembly and mental rotation. Children were presented with a model figure (i.e., a house), and they were asked to reproduce it on the side, by properly arranging its component parts (i.e., a square, a triangle, and a semicircle). Difficulty varied with the number, shape, and orientation of the components involved, including three (as described above, only one component must be rotated), three (an inclined parallelogram made of a square and two triangles, which would have to be rotated), and five components (i.e., a diamond made of a square and four triangles, all of which required rotation). Two scores were given for each item: 1 or 0 for the reproduction of the figure and 1 or 0 for the overall orientation; these scores were summed up into a total score ranging from 0 to 2 score for each item.

3.2.3.3. Deductive reasoning task. This task involved three items requiring to map permission rules onto their relevant pictorial representation (Goswami, 1996). Modus ponens, conjunction, and disjunction arguments were given. Specifically, a story was told about a character having to obey a rule in order to obtain something that she wanted. For example, according to the story addressed to modus ponens, (a) "One day Sally wants to play outside. Her mum says that if she wants to play outside, she must put her coat on". According to the story addressed to conjunction "One day Vera wants to play outside. Her mum says that if she wants to play outside, the weather must be nice and her room must be tide." According to the story addressed to disjunction, "One day Peter wants to eat a kind of fruit. His mum says that he can have either watermelon or banana, only if he eats his lunch." To ensure that they could follow the rule, children were asked to repeat it. Then they were presented with 4 pictures, one showing the character obeying the rule and the rest disobeying it. Performance on each item was scored from 0 to 3 to reflect their understanding of the rule and its matching with the proper pictorial representation. Scoring was based on both the selection of the correct picture and the explanations given for this selection: 0 for both wrong choice of picture and failure to repeat the rule; 1 for choosing the right picture but failing to repeat the premises of the rule or for choosing a wrong picture but correctly repeating the premises; 2 for choosing the right picture and partially repeating the rule; 3 for choosing the right picture and fully repeating the premises.

3.2.3.4. Analogical reasoning. Three analogical reasoning tasks, (i.e., with quantitative, spatial, and verbal content) were used. In the quantitative task, which included three items, children were presented two dolls and two sticks, each involving a different proportion of white and red sections (bricks). The instruction to the child was as follows: "You see that each of these two dolls has a stick made of red and white bricks. Now, we will play a game where we will have to decide which of the dolls wins each time. The doll "*having more red bricks compared to the white bricks in his stick wins the game*". Children were also asked to explain their answer. The three items were as follows (a) 1 red : 3 white :: *3 red* : *1 white*; (b) 3 red : 3 white :: *3 red* : *2 white*; (c) *2 red* : *1 white* :: 3 red : 2 white (the right answer shown italics).

The spatial task involved three items. Children were presented a target figure with a certain pattern, and three alternative figures. The instruction was: "Let's find out which of these figures (showing the three alternatives) matches this one as much as possible" (pointing to the target picture). Children were asked to explain their answer. Fig. 1 shows an example.

The verbal task involved three items. Children were first presented three pictures, where the first two formed the first part of an analogy, and the third was the first component of the second part. Then, children were asked to select from four alternative pictures the one that would complete the analogy, and explain their answer. The three items were (a) bird : nest :: dog : ? (Choose among *doghouse*, dog, cat, bone; right answer in italics); (b) bottom of sea : fish :: sky : ? (Choose among *bird*, sky, airplane, sun); (c) puppy : dog :: baby : ? (Choose among *adult*, baby, kitten, baby's toys).

Each analogical item was scored 0 (both answer and explanation were wrong), 1 (right answer but no explanation), 2 (right answer but explanations indicating focusing on one dimension, i.e., to the number of the cubes or to the shape of the figure or to the one part of the analogy) and 3 (right answer and explanations indicating understanding of relations between ratios or understanding the common pattern among figures or grasping the relation between classes). The inter-rater reliability was very high (97%).

The presentation order of the three tasks was randomized but the presentation order of items within each task was fixed.

3.2.4. Measures of self-awareness

Of the various aspects of consciousness mentioned in the introduction, only awareness of cognitive processes was examined here. In a separate session following the administration of the cognitive measures, children were asked to evaluate the relative difficulty and similarity between cognitive tasks. Six items were selected from the cognitive battery (two from each domain, clearly differing in difficulty) presented in separate pictures. Specifically, for quantitative thought, there was (1) a child adding three cubes and (2) a child adding five cubes. For reasoning, there was (3) a child hearing a story asking her to obey one rule and (4) a child hearing a story asking her to obey two rules. For spatial thought, there was (5) a child reproducing a figure consisting of three components and (6) a child reproducing a figure consisting of five components.

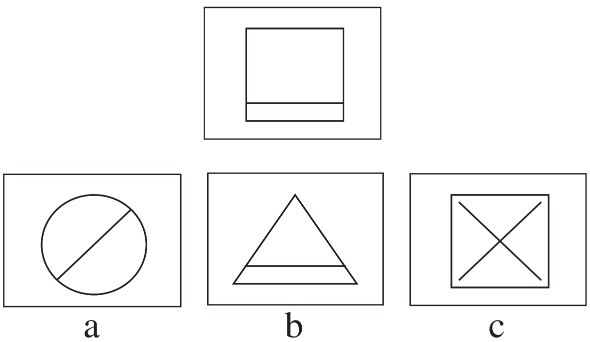

Fig. 1. Example of tasks addressed to spatial analogical reasoning. *Note*. Children were asked to choose which of the three bottom figures matches the top figure in the ratio of spaces marked by the dividing line(s) (b in this example).

Six pairs of pictures were presented to the children: (a) the two addition tasks, (pictures 1 and 2); (b) the two story-hearing tasks (pictures 3 and 4); (c) the two figure-reproduction tasks (pictures 5 and 6); (d) the easy addition and the easy story-hearing tasks (pictures 1 and 3); (e) the easy addition and the easy figure-reproduction tasks (pictures 1 and 5); and (f) the easy story-hearing and the easy figure-reproduction tasks (pictures 3 and 5).

To engage the participants in reflection about the mental activities of the children depicted in the pictures, the experimenter presented the tasks as follows: "These pictures show two children. Their teacher asked them to do some work. In this picture, the teacher asked this child to add *these* cubes (pointing accordingly). In this picture, the teacher asked this child to add *these* cubes" (pointing accordingly). Children were first asked to describe each picture in order to focus on the activities concerned. They were then asked to answer the following two questions: "Who of the two children is doing the *easier* job?" and "Is the job of *this* child the same as the job of *this* child?" (pointing accordingly). The same procedure was implemented for all six pairs. Thus, twelve scores (six difficulty estimations and six similarity estimations) were obtained. The presentation order of the six pairs of cards was randomized.

The first three pairs (a, b, and c) addressed comparison of tasks belonging to the same domain (quantitative, deductive, and spatial reasoning, respectively). The rest three pairs (d, e, f) addressed comparison of tasks belonging to different domains (quantitative–deductive, quantitative–spatial, and deductive–spatial, respectively). Comparisons of similarity and difficulty were scored as follows: 0 for wrong or irrelevant responses; 1 for answers referring to (or comparing) the perceptual similarity of the objects involved (e.g., "there are the same kind of cubes in the two pictures"; "the cube in this picture is similar to the square in this picture"); 2 for answers referring to (or comparing) the symbolic/generic characteristics of the tasks (e.g., "here he has cubes and here he has a figure to work on"; "cubes are easier than pictures"); 3 for answers explicitly referring to the mental operation or processes involved (e.g., "they are both counting"; "one is counting, the other is classifying"; "it's easier to count few than many cubes"; "it's easier to count than to understand a story, because once you have learnt how to count, you remember it forever"; "it's easier to understand a story than to count, because when you count you must be more careful not to make a mistake") (Demetriou & Kazi, 2001, 2006). This scoring reflects increasing levels of awareness about the cognitive processes involved in the tasks. Across all cognitive and self-awareness tasks, inter-rater agreement was very high (Mean = 98%).

3.3. Procedure

All measures were administered individually in a quiet room at school. Speed and control of processing, cognitive and self-awareness, and working memory measures were examined in four separate sessions. Each session included a familiarization phase. All but the cognitive and the self-awareness tasks were computer administered. All children, in both countries, were familiar with the computer, as this is part of their education.

3.3.1. Reliabilities

These batteries were very internally consistent in both ethnic groups. Cronbach's alpha for each of the four set of batteries described above was estimated separately for each ethnic group. The alpha values for Greeks were .98, .50, .87, and .87 for speeded performance, working memory, cognitive, and self-awareness measures, respectively; the corresponding values for Chinese were .96, .66, .86, and .84, respectively. The lower alphas of the working memory measures are due to the very small number of tasks involved.

4. Results

4.1. Age and ethnic differences

A series of analyses of variance (univariate and repeated measures analysis of variance) were run, in order to specify the effects of age, nationality, and their interactions. An overview of the statistically significant results is presented in Tables 2 and 3. These analyses are related to our first prediction concerning possible performance differences between the two ethnic groups in the various processes.

4.1.1. The development of processing efficiency

To specify the possible influence of age and nationality on the various aspects of processing efficiency, a series of analyses of variance were run on the various speeded performance measures. Specifically, a 4 (age groups) × 2 (nationalities) univariate analysis of variance was run on performance attained on the Simon task, the simpler of the speed of processing tasks used here. Results showed that reaction times decreased with age in both ethnic groups and that the Greeks were faster than the Chinese (see Table 2 and Fig. 2).

A 4 (age groups) × 2 (nationalities) × 3 (the three SSSs) × 2 (match vs. shift) repeated measures analysis of variance was run on the matching-control task. This analysis indicated that response times decreased systematically with age in both ethnic groups and that quantitative recognition was faster than object recognition which was faster than figure recognition. Also, matching tasks elicited faster responses than control tasks, although their difference diminished with age, indicating increasing control with development (see Table 2 and Fig. 2).

Finally, a 4 (age groups) × 2 (nationalities) × 3 (languages) × 2 (same vs. different symbols) repeated measures analysis of variance was run on the letter and ideograms task. It can be seen (Table 2 and Fig. 2) that the Chinese were always faster in logograph comparisons and they outperformed the Greeks in the other languages in the two younger age groups. It is noted that this analysis was re-run with the speed measures as covariates. This manipulation did not significantly affect the difference between the two ethnic groups.

It is noted that inspection of error rates did not reveal any differences between nationalities in the Simon, ($F(1,299) = 2.682$, $p > .05$, $\eta^2 = .01$, Mean = .199 and .162, for Greeks and Chinese, respectively), the matching ($F(1,299) = 1.426$, $p > .05$, $\eta^2 = .01$, Mean = .181 and .156, for Greeks and Chinese, respectively), or in the shift task ($F(1,299) = .942$, $p > .05$, $\eta^2 = .00$, Mean = .247 and .229, for Greeks and Chinese, respectively). However, there were significant differences between the two ethnic groups in the reading tasks, which are consistent with the findings above that Chinese children were more proficient in reading in Arabic ($F(1,299) = 8.516$, $p = .004$, $\eta^2 = .03$, Mean = .290 and .231, Std. Error = .015 and .014, for Greeks and Chinese, respectively), Chinese ($F(1,299) = 15.335$, $p < .0001$, $\eta^2 = .05$, Mean = .339 and .266, Std. Error = .014 and .013, for Greeks and Chinese, respectively), and Latin ($F(1,299) = 7.822$, $p = .005$, $\eta^2 = .03$, Mean = .261 and .202, Std. Error = .016 and .015, for Greeks and Chinese, respectively).

4.1.2. The development of working memory

To specify the possible influence of age and nationality on working memory, a 4 (age groups) × 2 (nationalities) × 3 (spatial memory vs. words vs. pseudowords) repeated measures analysis of variance was run. Table 2 and Fig. 3 show that working memory capacity increased with age in all dimensions, reaching the expected capacity of about 3 units at the age of 7 years (Pascual-Leone, 1970). Chinese children outperformed Greek children on the corsi and the pseudowords tasks. There was no noticeable difference on the words tasks, although Greeks tended to outperform Chinese in the two older age groups. This analysis was re-run with the speed and the reading speed measures as covariates. This manipulation did not significantly affect the difference between the two ethnic groups.

4.1.3. The development of cognitive abilities

To specify the possible influence of age and nationality on cognitive abilities, a 4 (age groups) × 2 (nationalities) × 4 (problem solving in quantitative, spatial, analogical, and deductive reasoning) repeated measures analysis of variance was run. Table 3 and Fig. 4 show that problem solving improved systematically throughout the age span studied in both ethnic groups. Chinese outperformed Greeks in all domains, but their advantage was larger in spatial and analogical reasoning. This analysis was re-run with speed, control, and working memory measures (the corsi and the words tasks) as covariates. This manipulation diminished significantly the difference between the two ethnic groups (η^2 of ethnicity dropped from .05 to .03). This effect was caused only from working memory (corsi: $F_{1,260} = 8.39$, $p < .004$; words: $F_{1,260} = 10.72$, $p < .001$) .

4.1.4. The development of self-awareness

To specify the possible influence of age and nationality on self-awareness, a 4 (age groups) × 2 (nationalities) × 2 (awareness of the similarity vs. awareness of difficulty) × 2 (within vs. across SSSs comparisons) repeated measures analysis of variance was run. Fig. 5 shows that awareness of cognitive processes improved systematically in both nationality groups. Chinese outperformed Greeks, especially in the evaluation of similarity of cognitive processes belonging to different cognitive domains (see also Table 3). This analysis was re-run with speed, control, working memory (the corsi and the words tasks), and the four cognitive measures as covariates. This manipulation completely annihilated the difference between the two ethnic groups (η^2 of ethnicity dropped from .05 to 0). This effect was caused only from reasoning (deductive

Table 2
Summary of results on speed and control of processing measures.

Analyses	Main and interaction effects of processes				The effect of age				The effect of nationality				The age × nationality interaction			
	F	df	p	η²	F	df	p	η²	F	df	p	η²	F	df	p	η²
Simon task					37.711	3, 240	0.0001	0.33	15.464	1, 240	0.0001	0.06	3.251	3, 240	0.05	0.02
The 3 SSSs (quantitative vs spatial vs categorical) × 2 types of processing (match vs. shift)					49.959	3, 192	0.0001	0.44								
The SSSs	19.025	2, 191	0.0001	0.17												
The types of processing	410.151	1, 192	0.0001	0.68												
The SSSs × age					6.087	3,192	0.001	0.09								
The 3 languages (Latin vs. Arabic vs. Chinese) × 2 type of symbol (same vs. different)					15.327	3,109	0.0001	0.30								
The languages	3.493	2,108	0.03	0.06												
The types of symbol	56.421	1,109	0.0001	0.34												
The languages × nationality									6.950	2,108	0.001	0.11				
The 3 types of memory (spatial memory vs. words vs. pseudowords)	457.556	2, 291	0.0001	0.76	69.464	3, 292	0.0001	0.42	36.073	1, 292	0.0001	0.11				
The types of memory × age					13.438	6, 584	0.0001	0.12								
The types of memory × nationality									33.135	2, 291	0.0001	0.19				

Note: Only significant results are presented.

reasoning: $F_{1,\,256} = 4.61$, $p < .03$); analogical reasoning: $F_{1,260} = 13.70$, $p < .001$).

4.2. The architecture of mental processes

The second hypothesis about the architecture of abilities claims that the architecture of processes would basically be the same in the two ethnic groups. To test this hypothesis, a series of structural equations models were tested using Bentler's (1995) EQS program. These models were tested on 20 measures standing for eight set of processes. Specifically, three measures for each of the following processes but quantitative problem solving, which was represented by two measures, were included in the analysis: (1) *spatial* and (2) *quantitative* problem solving, (3) *inductive* and (4) *deductive* reasoning, and self-awareness of similarity when comparing (5) *similar* and (6) *different* cognitive processes. Also, the (7) *spatial* (i.e., corsi) and the (8) *phonological* (i.e., words and of pseudowords) working memory measures were included. In addition, age and speeded performance measures were used in further tests of the model to be described below (see Appendix B).

The model shown in Fig. 6 implemented the architecture of mind specified in the introduction. Specifically, there was one first-order factor for each of the eight sets of measures specified above. The two working memory factors were related to a second-order factor standing for working memory. The quantitative and the spatial factor were related to a second-order factor standing for problem solving in the SSSs. The two reasoning factors were related to a second-order factor standing for inference. The two awareness factors were related to a second-order factor standing for consciousness. All second-order factors were related to a third-order factor standing for *g* as it was defined in the introduction. This is the basic model used as the source for all other models tested here.

This model was first tested on the performance of each of the two ethnic groups without any between groups equality constrains. The fit of the model was good, (χ^2 (330) = 436.65, p = .001, CFI = .94, SRMR = .08, RMSEA = .04, 90% confidence interval for RMSEA = .026–.044). This result indicated that, overall, the proposed factorial structure did fit both ethnic groups. One might object that a more parsimonious model might fit the performance attained by the two groups. To test this possible objection, a series of simpler models were tested and compared to the model above. Specifically, we first tested a model where there was only one working memory factor related to all three working memory tasks, only one cognitive factor related to all 11 cognitive tasks and one awareness factor related to all six awareness tasks. These three factors were related to one second-order *g*. The fit of this model was much weaker than the fit of the basic model (χ^2 (334) = 633.99, p = .001, CFI = .82, SRMR = .09, RMSEA = .06, 90% confidence interval for RMSEA = .052–.066). Alternatively, we tested a model which differed from the basic model only in not having the third-order *g* factor. Again, the fit of this model was much weaker than the fit of the basic model, (χ^2 (331) = 770.89, p = .001, CFI = .74, SRMR = .21, RMSEA = .07, 90% confidence interval for RMSEA = .065–.079). Therefore, the basic model is a strong basis for a more detailed comparison of the two ethnic groups.

The basic model did not speak about possible differences between the two ethnic groups in the strength of the proposed relations. To obtain this information, a fully constrained model was tested. That is, all relations in the model (i.e., the relations of performance measures with first-order factors, of the first-order factors with their corresponding second-order factors, and of the second-order factors with the third-order factor) were constrained as equal across the two ethnic groups. The fit of this model was worse than the fit of the model which did not include any equality constraints, (χ^2 (348) = 531.76, p = .001,

Table 3
Summary of results on cognitive and hypercognitive measures.

Analyses	Main and interaction effects of processes				The effect of age				The effect of nationality				The age × nationality interaction			
	F	df	p	η^2	F	df	p	η^2	F	df	p	η^2	F	df	p	η^2
The 4 cognitive domains (quantitative, spatial, analogical, and deductive thought)	14.409	3, 289	0.0001	0.13	108.025	3, 291	0.0001	0.53	9.960	1, 291	0.0001	0.10	5.852	9, 873	0.0001	0.06
The cognitive domains × age					4.810	9, 873	0.0001	0.05								
The 2 types of self-awareness (of the similarity vs. of difficulty) x 2 types of comparison (within vs. across SSS)					59.786	3, 290	0.0001	0.38	23.165	1, 290	0.0001	0.07				
The type of self-awareness	114.998	1, 290	0.0001	0.28												
The type of comparison	122.627	1, 290	0.0001	0.29												
The ype of self-awareness × type of comparison	43.232	1, 290	0.0001	0.13												
The type of self-awareness × age					3.725	3, 290	0.05	0.03								
The type of self-awareness × nationality									15.892	1, 290	0.0001	0.05				

Note: Only significant results are presented.

CFI = .89, SRMR = .14, RMSEA = .05, 90% confidence interval for RMSEA = .037–.053), indicating that the two ethnic groups differed in the strength of some relations.

Based on the Langrange multiplier test for releasing constraints, the constraints that did not hold were released. These were as follows: (a) the relation of the analogical performance measures to their corresponding first-order factor (Induction); (b) the relation of the first-order factor standing for Deduction to the second-order factor standing for Inference; (c) the first-order factor standing for Self-awareness of similarity when comparing tasks addressing Different Cognitive Processes to the second-order factor standing for Consciousness. This is the first of the two models shown in Fig. 6, where the relations constrained to be equal between groups are printed in bold. After removing the above mentioned constraints, (χ^2 (330) = 436.65, p = .001, the fit of the model was better than the one which did not include any constraints, (χ^2 (343) = 398.936, p = .02, CFI = .967, SRMR = .025, RMSEA = .025, 90% confidence interval for RMSEA = .011–.035, $\Delta\chi^2(13) = 37{,}71$, p < .001).

This model was retested after partialing out the effect of age and speed of processing. Technically, to partial out these effects, each of the 20 measures was regressed on age and the mean of speed of performance tasks, in addition to the factor each measure was related to. Validating the stability of the architecture of cognitive processes is theoretically and practically important. From the point of view of theory, the effects of development on cognitive architecture are still debated. Specifically, cognitive developmental theory would predict that, with increasing age, cognitive processes tend to get organized in more inclusive structures (Piaget, 1970). Differential theories would predict, based on Spearman's law of diminishing returns, that they would tend to differentiate in more specific abilities (Jensen, 1998; Spearman, 1927). Therefore, this manipulation was a strict test of the factorial structure proposed here because it could show if the structures and relations assumed would survive the removal of two powerful factors of developmental (i.e., age) and functional (i.e., speed) cohesion of cognitive processes. Practically, it was important for the comparison of the two ethnic groups to show, based on the second prediction, that the mental architecture is developmentally and functionally stable in both groups. The fit of this model when partialing out age and speed was very good, (χ^2 (351) = 452.81, p = .000, CFI = .96, SRMR = .02, RMSEA = .02, 90% confidence interval for RMSEA = .022–.039). This is the second model shown in Fig. 6. Interestingly, the effect of age on all measures, in both ethnic groups (mean regression coefficient of the 20 measures on age was .46 and .41 for the Greek and the Chinese children, respectively), was much stronger than the corresponding effect of processing efficiency (mean regression coefficient of the 20 measures on processing efficiency was .12 and .09 for the Greek and the Chinese children, respectively).

4.3. Strength of relations between processes

The third prediction is concerned with possible differences between the two ethnic groups in the strength of relations between processes. To test this prediction, a series of structural models were tested which examined the direct relations between the various constructs as represented by the second-order factors (see Fig. 7). Attention is drawn to the fact that in these models the problem solving and the

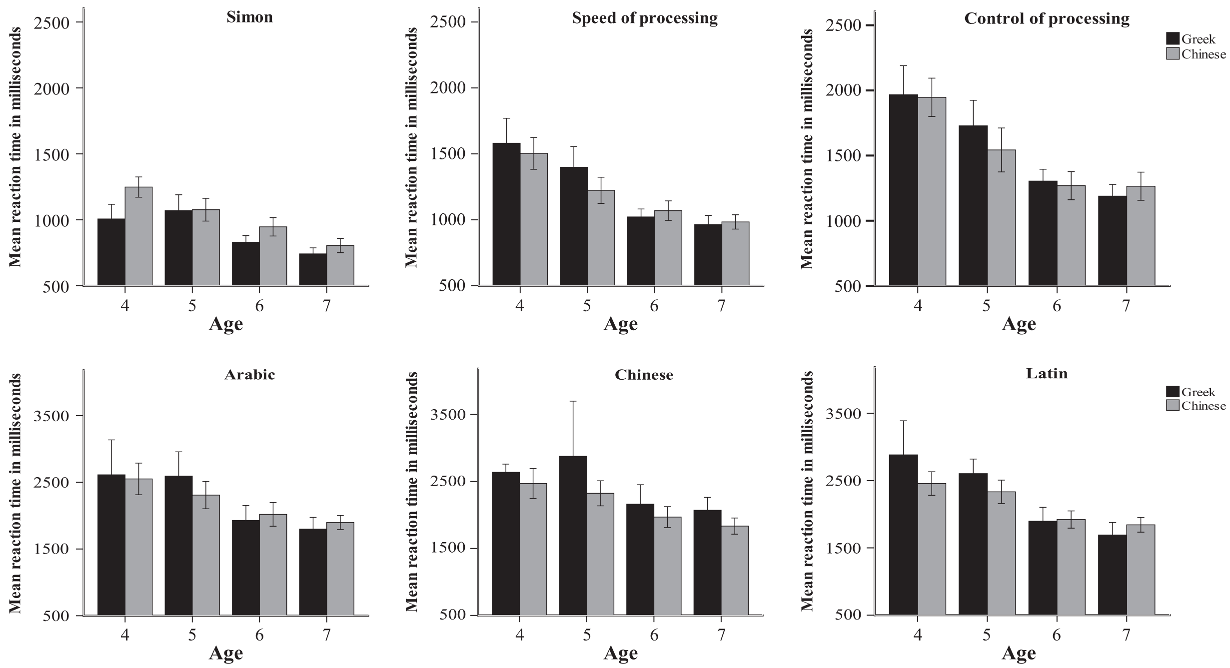

Fig. 2. Reaction times on speed of processing, control of processing, and letter recognition tasks across age and nationality. *Note*. Error bars indicate ±2 *SE*.

reasoning tasks were related to a common factor. Given the content of the problem solving and reasoning tasks used, this factor may be taken to stand for psychometric fluid intelligence (g_f). This factor was regressed on all other factors and age to specify the relative contribution of each to its condition. Based on the third prediction about possible effects of practice on a cognitive process, three models were run, their only difference being in the processing efficiency factor. This was first defined by the three matching tasks ($\chi2$ (309) = 352.98, p = .04, CFI = .97, SRMR = .07, RMSEA = .03), then by the three control tasks ($\chi2$ (309) = 346.50, p = .07, CFI = .97, SRMR = .07, RMSEA = .02), and, finally, by the letter comparison tasks ($\chi2$ (309) = 412.99, p = .00, CFI = .93, SRMR = .08, RMSEA = .04). The fit of all three models was good.

This model was highly informative about the structural relations between processes and the differences between the two ethnic groups. Specifically, the total effect of age on g_f was very high (accounting for between 72% and 81% of the variance in all models). However, a significant part of this effect was indirect rather than direct (between 25% and 36%), mediated by other factors, mainly WM. Interestingly, there was no direct effect of any of the three processing efficiency constructs used in the three models on g_f. However, age was strongly connected to processing efficiency and working memory and moderately to consciousness.

The differences between the two ethnic groups were informative. First, the age-speed (matching tasks) or age-control (shift tasks) relation was very similar in the two ethnic groups (circa .6) but the age-letter recognition speed relation was very different (i.e., 0 vs. .4 for Greeks and Chinese, respectively). Second, the age-WM relation was much stronger in the Chinese. However, the speed-WM or control-WM relation was much higher in the Greeks. Third, WM effects on g_f were higher in the Chinese. These results, which are in line with our third prediction about the relations between processes, will be discussed below.

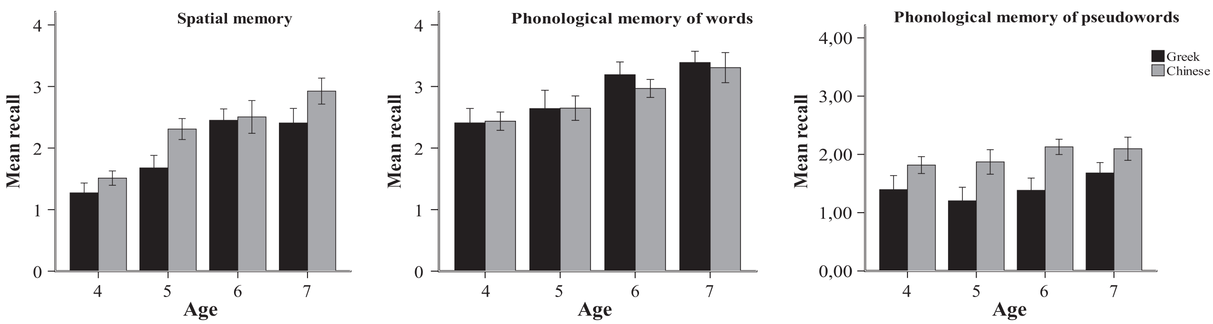

Fig. 3. Performance on working memory tasks as a function of age and nationality. *Note*. Error bars indicate ±2 *SE*.

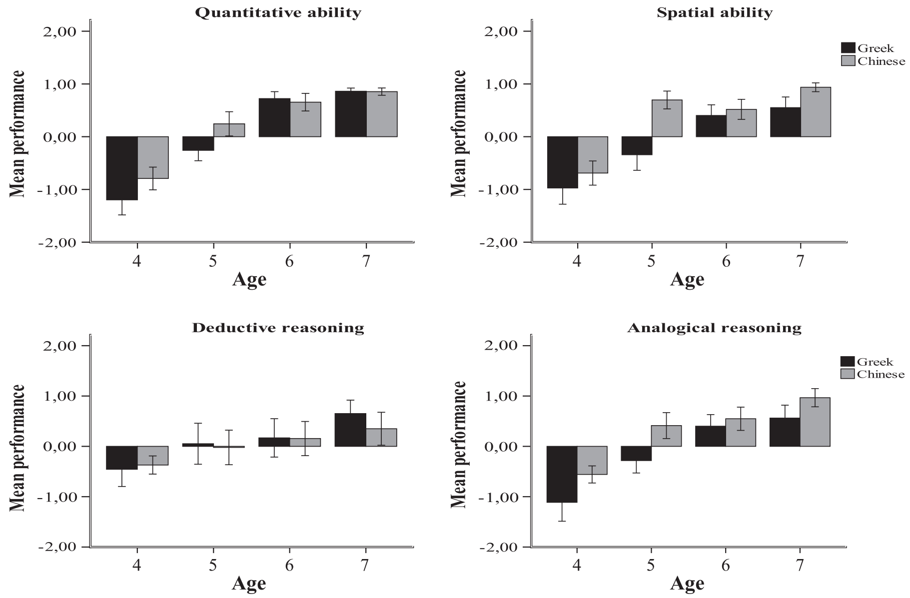

Fig. 4. Performance (z-scores) on cognitive domains across age and nationality. *Note*. Error bars indicate ±2 *SE*.

5. Discussion

The present findings were highly informative for both the development and the organization of cognitive processes at a very early age and the long debate about cultural influences on their development and organization. It is reminded that, in agreement with our first prediction about performance differences, we found that Chinese outperformed Greeks from as early as the age of four years in fundamental processes that may be associated with writing. However, we also found that Chinese outperformed Greeks in more general thought and self-awareness processes from this early age, although it might have been predicted that possible differences in these processes would need time to appear. In agreement with our second prediction, the overall organization of cognitive processes was the same in the two ethnic groups. However, in agreement with our third prediction about possible differences in the strength of relations between processes, we did find that reading-related processing efficiency was more closely related with working memory and that working memory was more closely related to inference in the Chinese. Bearing in mind the possible limitations in the representativeness of our samples and also the possible

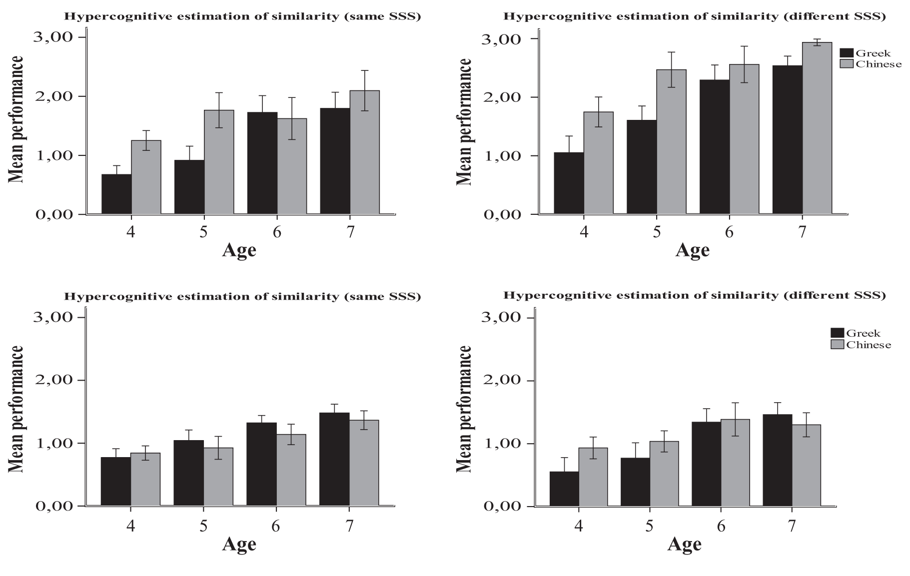

Fig. 5. Performance on hypercognitive evaluation tasks across age and nationality. *Note*. Error bars indicate ±2 *SE*.

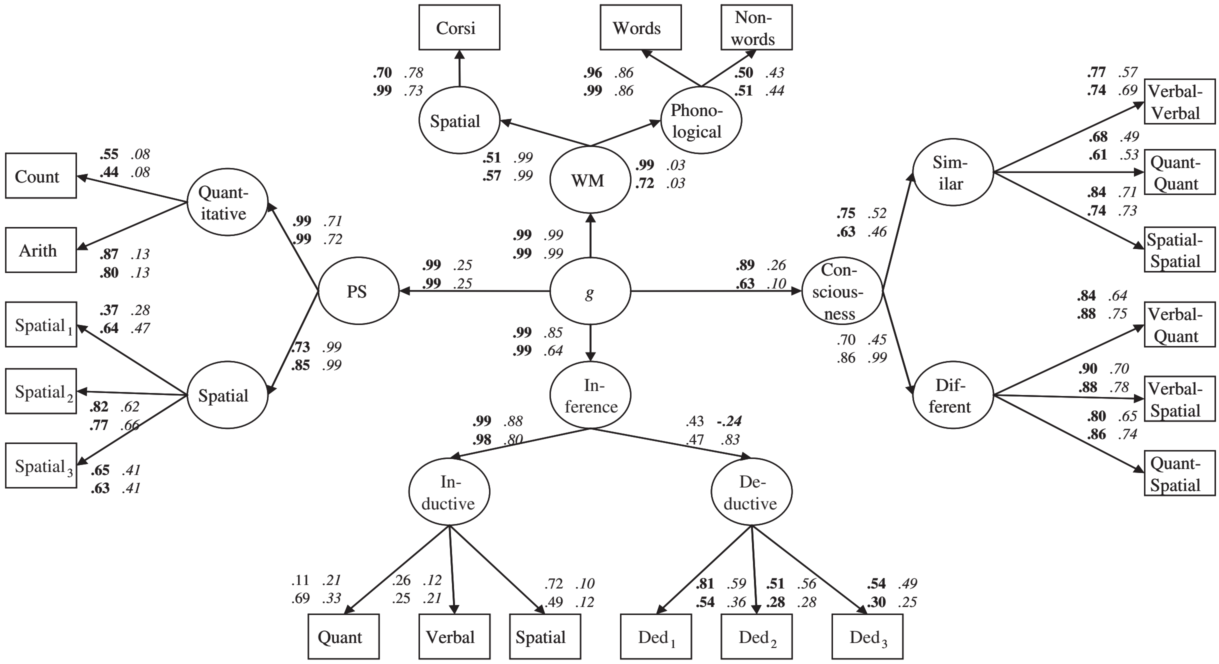

Fig. 6. Hierarchical model (standardized parameters) of the performance attained on the various tasks by Greeks (numbers on the top) and Chinese (numbers at the bottom of each set) before (roman, χ2 (343) = 398.94, p = .02, CFI = .97, RMSEA = .025), and after (italics, χ2 (351) = 452.81, p = .00, CFI = .96, RMSEA = .031) partialling out the effect of age and speed. Numbers in bold indicate equality constraints across cultures.

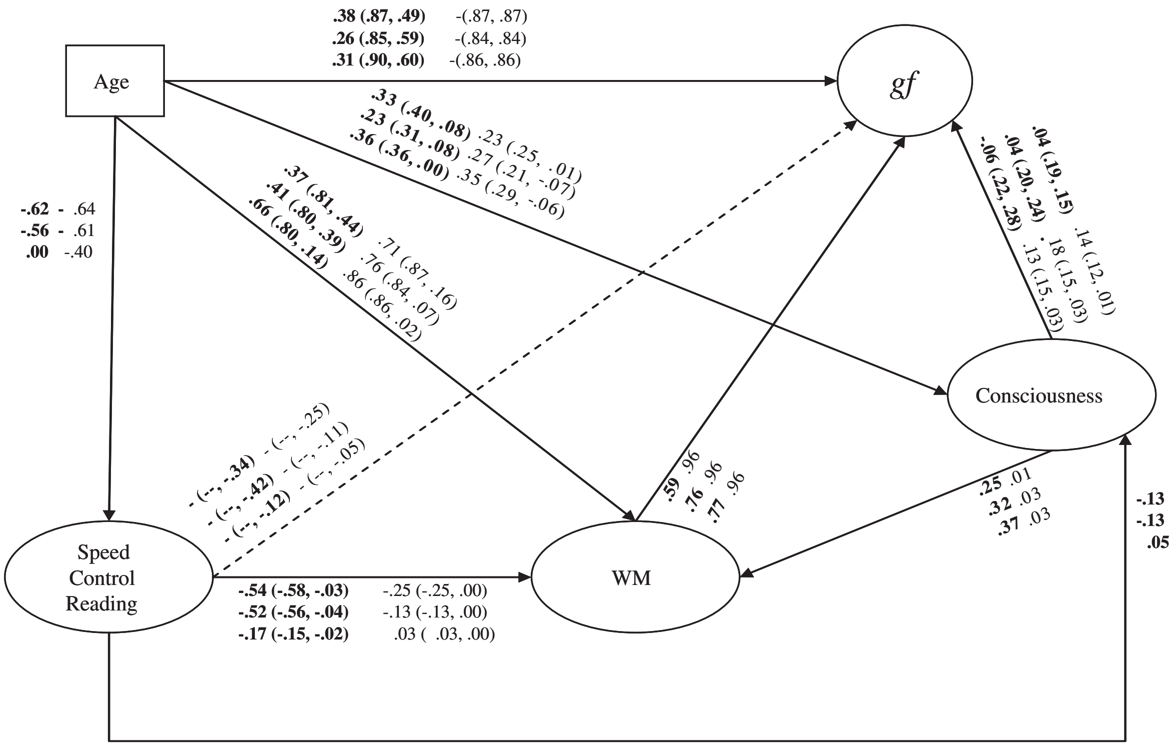

Fig. 7. Structural equation model of the relations between constructs across culture (Greeks in bold). In three successive runs of the model, the processing efficiency factor was specified in reference to the speed of processing, χ2 (309) = 352.98, p = .04, CFI = .97, SRMR = .07, RMSEA = .03, control speed, χ2 (309) = 346.50, p = .07, CFI = .97, SRMR = .07, RMSEA = .02, and reading speed, χ2 (309) = 412.99, p = .00, CFI = .93, SRMR = .08, RMSEA = .04. Dashes indicate relations dropped from the model. Numbers in parentheses show total and indirect effects of age on the constructs concerned.

lack of full equivalence in learning experiences other than the writing system, we attempt below to advance a comprehensive explanatory model for our findings.

Overall, the similarities in attainment and organization emerged as a very powerful finding of this study. We take these similarities to suggest the operation of a common baseline in the development and the organization of the developing mind that was the same in both cultures. However, the mind is a system for responding to and coping with variations in the environment. In fact, this is the role of the brain itself, the seat of the mind (Striedter, 2005). Therefore, systematic ethnic differences in experience may be expressed as differentiations of this common baseline in the organization and functioning of the mind. Specifically, the pattern of similarities and differences observed in performance and organization suggested that experience-specific differences, when repeated and systematic, generalized to seemingly unrelated processes through their effects on the dynamic relations between the various representational and processing systems of the mind.

In line with this interpretation, the differences between Greeks and Chinese in processing efficiency and representational capacity, the two supposedly most fundamental systems of mental processing, were limited to aspects that could be directly associated with the writing system. In processing efficiency, Chinese always outperformed Greeks in the logographic system and, at the beginning, in letter recognition in general. Later on, Greeks caught up in the systems in which they acquired practice. Interestingly, Greeks outperformed Chinese on the Simon task, which appears less related to the early learning needs of the logographic writing. That is, Chinese, because of their logographic-specific experience, may have developed a more careful general stimulus search strategy that was advantageous in tasks where complexity exceeded a certain limit. However, this experience may not have provided any advantage in very simple tasks where plain stimulus identification was required. In the same line, Chinese outperformed Greeks on visuo/spatial and the pseudowords tasks working memory tasks, which were advantageous to them, but not on the words tasks where they seemed not to have any advantage. All in all, Chinese excelled in processing efficiency and representational capacity only where they have had a cultural advantage. Notably, the stability of ethnic differences in these measures even when other possibly related measures such as speed were used as covariates indicated that this cultural advantage impacted directly and stably the cognitive processes involved.

However, this advantage appeared no less important in its far reaching consequences, because it spread to higher level processes, for three inter-dependent reasons. First, spatial memory is normally directly involved in a wide array of everyday activities, such as orientation and navigation, discourse comprehension, information search, spatial thinking, and reasoning, causing a better grasp of concepts and relations in the environment. Second, being immersed in a logographic culture early in development seemed to enhance the command of working memory. This may have generated a general advantage in information processing and problem solving, because "*g* appears related to the ability to flexibly and consistently reconfigure the contents of working memory." (Larson & Saccuzzo, 1989, p. 5). The reduction of g_f differences between the two ethnic groups when working memory was used as a covariate provided support to this interpretation. In the long run, third, this experience may have acted as mechanism for enhancing general cognitive fluidity by refreshing delicate information processing mechanisms and related brain functioning, benevolently affecting the dynamics of development as such, later in age. In conclusion, the logographic experience may keep persons closer to their cognitive potential, thereby enhancing their actual cognitive performance.

In concern to the organization of mental processes, in a nutshell, there were no differences in the overall mental architecture but there were some differences in the strength of relations between processes as a function of both age and nationality. Specifically, the results of SEM supported our predictions about a four-fold mind, involving SSS, representational capacity, inferential processes, consciousness and *g* as a higher-order integrative factor. This architecture was stable over age and nationality, although the strength of relations between processes varied as a result of development and cultural influences. Specifically, the stability of WM-*g* and inference (or *gf*)-*g* association after partialing out the effects of age suggested that early in development general intelligence seemed to depend primarily on working memory and inferential processes. Problem-solving, awareness of cognitive processes, and self-evaluation were gradually integrated in *g*, as a result of experience accruing with development. This was suggested by the dramatic weakening of the problem-solving-*g* and the consciousness-*g* association when the effects of age were partialed out. Also, the very low direct effect of speed of processing on all measures is notable in its implication that, in this age period, processing efficiency as such was not a crucial factor of intellectual development. Well organized and systematic experiences might have been more important.

We found, in line with the third prediction about differences in the strength of relations between processes, that the age-WM relations were stronger among the Chinese compared to the Greeks. We take this difference to indicate that Chinese children experienced more practice related to the operation of WM than Greek children. These experience aligned WM development with age better in the Chinese than in the Greeks. Furthermore, the much closer WM-g_f relations in the Chinese strongly suggested that their more efficient command of WM was expressed in the functioning of the problem-solving and inferential processes involved in g_f. It is highly interesting that consciousness was much more closely related with WM in the Greeks but much more with g_f in the Chinese. It seems that the Greeks needed the monitoring processes involved in consciousness more than the Chinese to handle the demands of WM tasks. On the other hand, Chinese started from this age to be more aware of cognitive processes, probably because they were forced to monitor and reflect on cognitive processes. This interpretation was strengthened by the fact that the difference between the two ethnic groups in self-awareness about cognitive processes was completely dependent on analogical and deductive reasoning. In conclusion, cognitive fluidity resided in the interaction between systems in both groups, but differences in experience accentuated different paths in the two cultures, explaining their relative differences in developmental rate and, eventually, the possible formation of different kinds of mind (Nisbett, 2003).

Shall we all learn Chinese? This is obviously not possible. However, education may design powerful environments with the use of modern technology that can compensate for what we miss by not learning Chinese! This would focus on educating attention control, flexibility in shifting between stimuli and/responses, integration between information in working memory and long-term memory, model construction relative to problem goals, and awareness of inferential processes (Demetriou et al., 2011). In effect, interventions of this kind would be a good test of the theory and ideas advanced here.

Any cross-cultural comparison of the kind attempted here is constrained by many limitations. These come from the fact that it is very difficult for the researcher to establish that any differences between ethnic groups in cognitive organization or attainment are indeed related to the causes hypothesized than to other unknown causes. For example, the pattern of cross cultural similarities and differences found here led us to an interpretation leaning towards a cultural interpretation of the origins of differences. Others might prefer an evolutionary or genetic interpretation (Jensen, 1998; Rushton & Jensen, 2005). In line with the genetic interpretation, some recent studies connected the Chinese advantage in processing speed to a specific gene variant that allows Chinese to be faster in processing speed than Western populations (Beaujean, 2005; Chang, Kidd, Kivak, Pakstis, & Kidd, 1996; Hansell et al., 2005; Lee et al., 2012; Szekely et al., 2010). Nevertheless, on the one hand, a genetic advantage for faster processing speed would have to be present in all speeded performance measures and not only to those related to reading, as found here. On the other hand, the existence of differences between the two ethnic groups in thought and self-awareness from this early age might suggest the operation of many other factors. For example, there may be other language differences between Greek and Chinese, in addition to writing, such as the structure of language, which may influence cognition. Also, there may be differences in cultural practices at home and in the classroom that relate to learning and intellectual development which differentiate the two cultures in the long run. Therefore, the origin of differences is an open question for future research. An interesting question would be to examine how, if at all, possible cultural differences in genetic predispositions related to mental processing may interact with the establishment of culture-specific mindtools, such as writing. It might be the case that these interactions underlie long-term cycles of evolutionary and cultural selections which resulted in the present differences in intelligence between nations or cultures and they may even generate more differences in the future. Another question would be to examine how, if at all, systematic differences between the two languages in morphology and grammar, syntax, and semantics, are related to differences in intellectual development and performance (Sampson, Gil, & Trudgill, 2009). Finally, another question would be to examine how subtle differences in learning related cultural practices in the school and outside of it are related to the patterns of intellectual differences observed here. A future study addressed to these questions would have to overcome the limitations of the present study. That is, it would have to equate children in background factors, such as brain-related, language-related, family-related, and learning-related variables more precisely than it has been possible here. This would enhance our understanding of the human mind, its development, and its interaction with culture.

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Appendix A. Supplementary data

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