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Self-awareness in *g* (with processing efficiency and reasoning)

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Abstract

This article presents three studies that were designed to map the dimensions involved in *g*, with an emphasis of the place of self-awareness in it. The first study involved preschoolers from 3 to 7 years of age. These were examined in three domains (spatial, quantitative and categorical reasoning) with both actual tasks and tasks addressed to the awareness of the cognitive processes involved in the tasks. The second study examined 11 to 16 year olds in five domains: quantitative, causal, social reasoning, drawing, and ideational fluency. Participants solved two tasks in each domain; they were asked to evaluate their performance on each task, and they answered an inventory addressed to perceived competence in each of these five domains. The third study examined participants from 11 to 15 years of age with tasks addressed to processing efficiency and capacity, reasoning, and perceived competence in three domains (quantitative, verbal, and spatial cognition). Confirmatory factor models involving first-order domain-specific factors, second-order process-specific factors, and a third-order general factor having very strong and more or less equal relations with the second-order factors were always found. General efficiency and domain-specific processes are accurately projected into self-awareness. The accuracy of self-awareness functions was found to develop with age. The implications of these findings for the general theory of intelligence and intellectual development are discussed.

Keywords: Cognitive development; General intelligence; Processing efficiency; Reasoning; Speed of processing; Self-awareness; Self-evaluation; Working memory

The nature, composition, and functions of general intelligence have again become the focus of intensive theoretical and empirical interest in differential psychology, cognitive science, and neuroscience (Demetriou, 2002), a full century after Spearman (1904) has introduced and specified this construct. Three seem to be the reasons for the resurgence of interest in general intelligence. First, the theories that postulate that the human mind is a system of independent modules or frames (e.g., Gardner, 1983) were found to fall short of a satisfactory account of learning in formal and informal settings (Adey, 2004), for intellectual development (Case, 1985, 1992; Demetriou, 2004; Halford, Wilson, & Phillips, 1998), and everyday functioning (Gottfredson, 2003). Specifically, there is now strong evidence that some very general processes, such as working memory and speed of processing, are closely related to learning and performance in a variety of contexts and intellectual development. Second, the development of new methods for mapping the functioning of the brain, such as PET and fMRI, allow the specification of the neuronal basis of cognitive processes and they can, therefore, enable the student of intelligence to uncover the brain equivalent of the functional structures and relations revealed by psychological research. The use

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of these methods has recently generated evidence suggesting strongly that some brain structures, mainly located in the prefrontal cortex, are clearly related to psychometric *g* (Duncan et al., 2000; Haier, Jung, Yeo, Head & Alkire, 2004). In the same direction, research in artificial neural networks suggests strongly that there are general mechanisms underlying learning and development in different domains (Shultz, 2003). Finally, the development of new statistical methods, such as structural equation modeling and dynamic systems modeling and related computational technology, allow the specification of relations between cognitive processes and abilities in ways that were not possible until recently. Many recent studies using confirmatory factor analysis and structural equation modeling suggest strongly that a general factor does exist (Demetriou, Christou, Spanoudis, & Platsidou, 2002; Gustafsson, 1984; Gustafsson & Undheim, 1996).

Despite the progress achieved, we are still a long way from a commonly acceptable model of the nature, structure, and functions of *g*. Although it is accepted that *g* is what is common between all cognitive processes (Carroll, 1993; Jensen, 1998; Spearman, 1904), there is no agreement as to how this commonality is to be defined. In fact, there are three interpretations of it, which, although compatible, are clearly different from each other. First, according to its initial interpretation, *g* reflects the state of general inferential processes, such as deductive, inductive, and analogical reasoning, that enable humans to integrate information in order to construct concepts about the environment, learn new information and skills, and solve novel problems by flexibly using extant knowledge and skills. Spearman's (1904) induction of relations and correlates, Cattell's (1971) fluid intelligence, and Piaget's operative intelligence (Piaget, 1970) are instantiations of this interpretation of *g*.

Second, according to a latter interpretation, adopted by many modern researchers with Jensen (1998) at the lead, *g* is a biological rather than a psychological construct that reflects the efficiency and capacity of the brain to represent and process information. From this point of view, *g* is defined in terms of domain-free functional manifestations of efficiency and capacity, such as speed of processing and working memory. These processes constrain the complexity and, to a considerable extent, the kind of information that can be represented and processed at a given point in time. In fact, according to this interpretation, the state of inferential processes can be reduced to the state of processing potentials to a very large extent (Baddeley, 1990; Colom, Abad, Rebollo, & Shih, in press; Jensen, 1998; Kail, 1991; Kyllonen & Christal, 1990; Pascual-Leone, 1970; Stankov & Roberts, 1997).

Several scholars in this tradition generated evidence suggesting that executive control as such, rather than processing efficiency or capacity, is the central core of general intelligence. Executive control is defined as the ability to stay focused on goals and organize actions so as to attain goals as efficiently as possible, by appropriately selecting the stimuli to be attended to and the actions to be performed and inhibiting the processing of irrelevant information or the execution of irrelevant actions (Conway, Cowan, Bunting, Therriault, & Minkoff, 2002; Engle, Tuholski, Laughlin, & Conway, 1999). In a similar vein, developmental researchers argue that executive control drives the development of reasoning and other inferential abilities (Frye, Zelazo, & Burack, 1998; Zelazo & Frye, 1998) and processes that imply awareness of mental processes such as theory of mind (Perner & Lang, 1999).

Finally, some theorists of intelligence argue that general intelligence also involves directly knowledge and problem solving skills and processes underlying self-monitoring, self-evaluation, self-representation, and self-regulation. These processes enable the person to capitalize on his or her thinking activity by forming increasingly more accurate maps of mental activity and problem-solving processes so as to be able to direct decision-making regarding problem solving as efficiently as possible (Demetriou & Efklides, 1989; Demetriou, Efklides, & Platsidou, 1993; Demetriou & Kazi, 2001; Flavell, Green, & Flavell, 1995; Sternberg, 1985). Although some recent studies have shown that some aspects of self-awareness, such as self-confidence and self-evaluation of intellectual performance, stand out as autonomous factors side by side with fluid intelligence (Stankov, 2000), psychometric research and theorizing paid very little attention to this aspect of intelligence. It is notable that classic books about *g* (Jensen, 1998) and the structure of intelligence (Carroll, 1993) are completely silent about these processes. In fact, even in the research focusing on executive control, which by definition involves some kind of self-awareness, self-awareness is assumed rather than directly studied. As a result, our understanding of the place of the various aspects of self-awareness in *g* and of their relations with processing efficiency and inferential processes is very weak.

The three studies presented in this article were designed to zoom in on the internal architecture of *g* with the aim to specify the relative strength and relations of processing efficiency and capacity, inferential processes, and self-awareness processes. Specifically, in each of these studies two of these systems (the first two studies) or all three of them (the third study) were directly addressed, with an emphasis on the place of self-awareness, which was examined in all three studies. That is, in all three studies we tried to specify the contribution of self-awareness to the formation of *g* relative to other processes related to mental efficiency and reasoning. The general model tested in all three studies was a hierarchical model involving first-order domain-specific factors, second-order process-specific factors, and a third-order general factor. Moreover, the three studies are complementary to each other in regards to the age of the participants involved. Specifically, taken together, the three studies cover the age range from 3 to 16 years. Therefore, these three studies are unique in their possibility to specify the relative contribution of these processes to the formation of general intelligence during a period of life that is very important for the development of intelligence and illuminate the role of various aspects of self-awareness.

1. Study 1: self-awareness of cognitive processes in early childhood

Are young children aware of the cognitive processes activated by different kinds of cognitive tasks? How is awareness of cognitive processes, if any, related to actual performance on cognitive tasks? Piaget (2001) himself believed that awareness about one's own cognitive processes comes with formal operations. Therefore, it is a late attainment that comes in adolescence. More recent work, however, suggests that awareness about various aspects of cognitive functioning begins rather early in life. The acquisition of a theory of mind at 3–4 years of age indicates that preschoolers have a fundamental understanding of the representational and interpretive character of the mind (Perner, 1993; Wellman, 1990). Moreover, Flavell and his colleagues have shown that preschoolers differentiate thinking from other cognitive (e.g., perception) and noncognitive activities (e.g., movement). However, they do not yet understand how thinking is activated or how it works (Flavell et al., 1995). In the same direction, Fabricius and Schwanenflugel (1994) showed that from the age of eight years children start to be able to differentiate between cognitive functions that are clearly different, such as memory and inference. However, it is only later on that individuals can distinguish between different variants of a general cognitive function, such as different kinds of memory. This study aimed to examine systematically how sensitive preschoolers are to cognitive processes activated by different domains of thought and how this sensitivity is related to actual performance in the same domains.

1.1. Participants and tests

1.1.1. Participants

A total of 100 children were examined. Specifically, 20 children, equally drawn among males and females, were examined from each of the age years 3 through 7. All of the children were Greek and came from middle class families leaving in the major Thessaloniki area, which is a city of about 1.2 million inhabitants. The three younger age groups involved children from three nursery schools. The two older age groups involved pupils from the first and the second primary school grade.

1.1.2. Cognitive tasks

Children were tested in three domains of reasoning, namely mathematical, categorical, and spatial reasoning. Each domain was addressed by two tasks.

The mathematical tasks addressed counting and arithmetic operations. For counting, subjects were asked to count up to 12 objects arranged either in a line or randomly. Counting started from 2 objects and it stopped after two failures in succession. One point was credited for each successful trial. The arithmetic operations task involved 12 items organized in four levels of difficulty. In the four levels, the result of the operation was up to 3 (e.g., 2+1), 5 (e.g., 3+2), 7 (e.g., 3+4) and 11 (e.g., 7+4), respectively. Two items in each level required addition and one required subtraction. Each item was actualized by the experimenter by putting in or taking from a box as many cubes as specified (e.g., first 2 and then 1 cube) and asked the child to specify "how many cubes are in the box now." It was assumed that asking the child to specify the results of each of the two sequences of putting in or taking objects from the box would direct the child to execute the arithmetic operation required rather than simply count the objects involved. One point was credited for each item answered successfully.

The categorical tasks addressed classification. One of the tasks involved different types of vehicles and the other involved geometrical objects. Specifically, in the vehicles task children were asked to classify various types of toy vehicles. Again, there were four items whose difficulty varied according to the type (flying vehicles, such as airplane and helicopter, sea vehicles, such as ship and boat, and wheel moving vehicles, such as car, bus, and lorry) and the number of the items involved. In the geometrical objects tasks children were presented randomly arranged cubes and parallelepipeds of different colors and were asked to "put together those objects that belong together." There were four items whose difficulty varied according to the type (only parallelepipeds or cubes and parallelepipeds), the number of items (4 or 6), and the distribution of colors involved. In the easy tasks objects of different shape were differently colored. In the difficult tasks some objects of different shapes had the same color. This manipulation provides the possibility to test if children can form exhaustive superordinate classes on the basis a single attribute (shape) ignoring possible similarities at a lower level (the color of some objects in each superordinate class) and explain accordingly. Each item was scored on a 4-point scale (0 for wrong answer and wrong explanation, 1 for right answer and no explanation, 2 for right answer and poor explanation, and 3 for right answer and satisfactory explanation).

Two visuospatial tasks addressed the ability to compose an object by properly arranging its component parts. The first task involved nine items requiring the reproduction of geometrical figures. Children were asked to reproduce a model figure on a blank card by properly arranging its component parts which were randomly arranged on the side of the model figure. Difficulty was manipulated by varying the number and the shape of the components involved. For example, the easiest was a circle made of two semicircles whereas the most difficult was a complex figure made of a diamond and four triangles, each attached to one of the diamonds sides. The second task was a wooden puzzle involving 6 pieces organized in three levels of depth. One, 2, and 3 pieces fit into the three levels, respectively. Children were credited one point for each piece that was placed at the right place.

1.1.3. Tests of awareness of cognitive processes

To examine if participants were aware of the processes activated by the various tasks described above, they were asked to compare pairs of tasks belonging either to the same or to different domains. Specifically, participants were presented with pairs of cards each of which showed a child trying to solve a task similar to those given to them and they were asked to evaluate if the tasks of the two children were similar to each other and explain their answers. There were nine pairs of cards. In sets of two, there were three pairs where the two children were required to use the same processes, applied either on the same or on different objects. Specifically, two of the pairs addressed classification (the two children were trying to classify the same objects in the first pair and different in the second pair), two addressed counting (the same objects in the first pair and different in the second), and two addressed visuospatial reasoning (reproduction of a model figure in the first pair and puzzle construction in the second). Finally, there were three pairs where the two children were required to use different mental processes. That is, in one pair one of the children was supposed to classify and the other to count. In another pair, one of the children was supposed to classify and the other to reproduce a model figure. Finally, in the last pair, the one of the children was supposed to count and the other to reproduce a figure.

Responses on each of these nine tasks was scored on a four-point scale as follows: 0 for wrong or irrelevant responses; 1 for answers indicating focusing on the perceptual similarity of the objects involved; 2 for answers indicating focusing on the symbolic/generic characteristics of the tasks (e.g., here he has cubes and here he has a figure to work on); 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 etc.).

Both batteries were very reliable. The alpha reliability for the cognitive and the self-awareness battery was .83 and .92, respectively.

1.1.4. Procedure

Children were tested individually during school hours by the second author. There was a warming up phase aiming to familiarize children both with the experimenter and the tasks before the main testing took place. This was judged necessary to ensure the rapport between children and the experimenter that is needed when very young children are involved.

1.2. Results and discussion

This study provides the evidence for a crucial test of the status and condition of self-awareness in the overall organization of the mind for two reasons, one concerning the age of the participants examined and the other the measures of self-awareness used. Specifically, the measures used in the present study, unlike the two following studies, addressed awareness of cognitive processes as such rather than perceived cognitive competence or success. Therefore, this study enables one to test how the subjective structure of cognitive processes is related to their objective structure at an age at which awareness of cognitive processes is supposed to be very crude.

To test these relations, the following model was fit on the six measures of cognitive performance (two for each domain of reasoning) and the nine measures of self-awareness (two for each domain of reasoning and three requiring cross-domain comparisons). First, each pair of domain-specific performance measures and each pair of domain-specific self-awareness measures was related to a different first-order factor which, therefore, stands, for performance or self-awareness within the respective domain. Second, the three domain-specific first-order performance factors were related to one second-order performance factor. This factor stands for general reasoning processes that underlie inference in all three domains represented here (**g**$_r$). This factor is very similar to psychometric *g*. Third, the three domain-specific self-awareness factors were related to another second-order factor that stands for general self-awareness (**g**$_{sa}$). The three measures requiring cross-domain comparisons of cognitive processes were directly regressed on this factor. Finally, the two second-order factors were regressed on a third-order factor, to be called the "grand *g*" (**G**$_{grand}$), to avoid confusion with the other general factors. This model is illustrated in Fig. 1 (the correlations between the variables included in this model and their statistics are shown in Table A1 in the Appendix). The fit of this model was satisfactory, χ^2 (81) = 140.964, p = .00, CFI = .943, RMSEA = .086, (10% confidence interval = .062–.109), and improved significantly when the error variances of three variables (specified in Fig. 1) were allowed to correlate, χ^2 (79) = 105.004, p = .03, CFI = .976, RMSEA = .058, (10% confidence interval = .021–085).

One might object here that the architecture and relations uncovered by this model reflects developmental differences in the rate of attainment of the processes reflected by the various tasks rather than genuine and stable differences in the organization and functioning of these processes. This objection is, in principle, justified by the fact that our participants were sampled from an age phase that is known to be associated with massive changes in all aspects of cognitive functioning. To test if the objection is empirically justified, the model above was re-ran with the effect of age partialled out from the relations of each observed variable with the factor each variable is associated to. Technically, this was effected by regressing each of the 15 observed variables included in the model on age, in addition to the factor they are associated to in the model presented above. The model proved to remain powerful in both its fit, the strength of

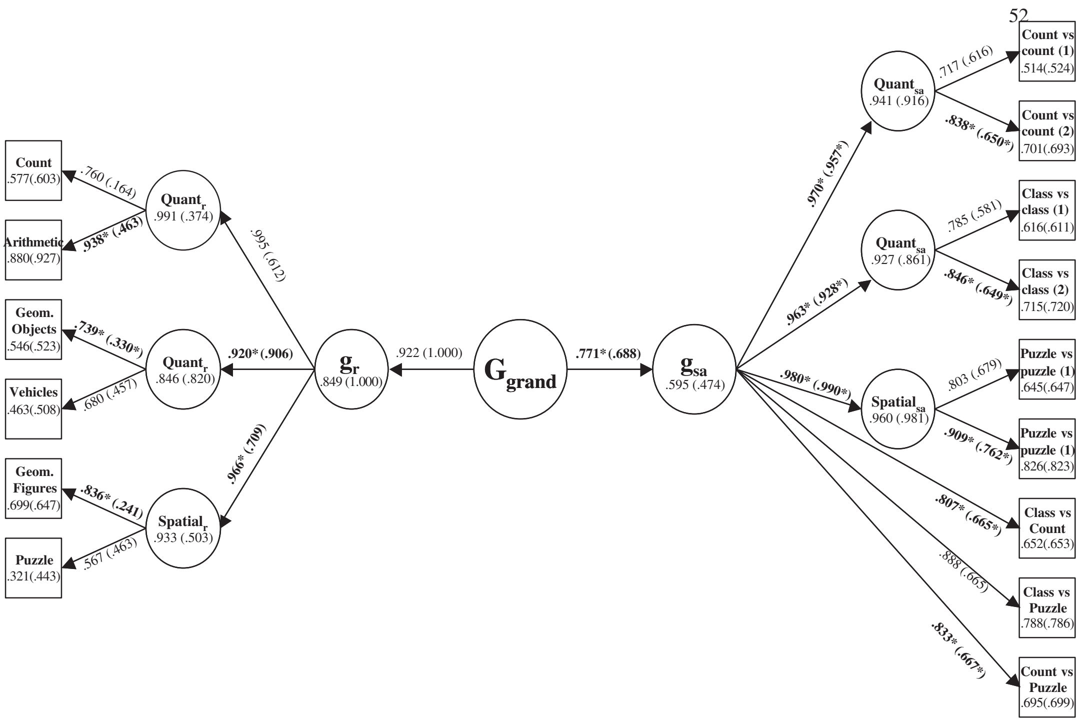

Fig. 1. The confirmatory factor analysis model for cognitive performance and self-awareness of cognitive processes examined in Study 1. Note 1: The first and the second coefficient in each pair represent relations before and after partialling out the effect of age. Free parameters are denoted by bold characters. Significant coefficients are denoted by asterisks. Numbers in squares and circles indicate variance accounted for. Note 2: The error terms of the following variables were allowed to correlate: (1) the wooden puzzle task with the evaluation of similarity between the counting and the wooden puzzle task, (2) the counting task with the evaluation of similarity between the classification and the wooden puzzle task, and (3) the evaluation of similarity between the classification task and the evaluation of similarity between the two counting tasks.

factors and the between factors relations after the effect of age was removed, χ^2 (79)=107.439, p=.02, CFI=.977, RMSEA=.061, 10% confidence interval for RMSEA=.026–.088. Attention is drawn to the fact that the relations of the two second-order factors with $\mathbf{G}_{\text{grant}}$ is very high in both models. It is clear, therefore, that self-awareness, as measured here, constitutes, together with $\mathbf{g}_r$, a strong component of g already from preschool age.

It may be noted here that the judgements of similarity between processes in the self-awareness tasks moved, with age, from the perceptual characteristics of the tasks compared to the mental operations involved. Specifically, from the age of 3 to 5 years, the majority of children based their judgements on perceptual similarity across all nine task pairs. More than half of 6-year-olds and more than the two thirds of the 7-year-olds the children were able to recognize that the three task pairs involving tasks belonging to a different domain require different mental processes. However, it was only at the age of seven years that the majority of children were able to recognize the mental process required by similar process tasks where the objects of application of the process differed. By that time, performance on the cognitive tasks approached ceiling.

Therefore, it is clear that actual cognitive performance and awareness of the processes activated by the various tasks covary closely from pre-school age. This indicates that there are common mechanisms that unite cognitive processing and concomitant awareness of it. It is worth mentioning that a series of recent studies generated evidence that is fully in line with the findings of this study. Specifically, these studies showed that various measures of processing potentials, such as working memory and executive control, are systematically related with the development of theory of mind (Davis & Pratt, 1995; Gordon & Olson, 1998; Perner & Lang, 1999). Moreover, Andrews, Halford, Bunch, Bowden, and Jones (2003) showed that the development of theory of mind is constrained by the same rules of complexity as other inferentially laden domains, such as transitivity and class inclusion. Therefore, it should not come as a surprise that Bradmetz (1998) showed that measures of psychometric g, such as verbal arithmetic, comprehension, and the Columbia maturity scale load on the same common factor with classical measures of theory of mind, such as false belief and understanding the mental states of other people as distinct of one's own mental states. Even more, there is evidence that the efficiency of selective and shared attention in infancy, as indicated by both speed of operation and flexibility in their functioning, is systematically related to intelligence later in childhood (Dougherty & Haith, 1997; McCall, 1994).

2. Study 2: reasoning, self-evaluation, and self-representation

The second study was similar to the first in some respects and different in others. Specifically, the cognitive processes examined in the present study only partially coincide with the processes examined by the first study. Specifically, this study addressed five domains of cognitive performance: mathematical, causal, and social reasoning, and also drawing and creativity. In as far as self-awareness is concerned, this study did not ask for comparisons between cognitive processes. Instead, this study examined self-evaluation of the performance attained on the tasks addressed to the participants and also perceived competence in the respective domains. Therefore, the design of this study allows one to specify how two complementary aspects of self-awareness, that is, self-evaluation and self-representation, are related to cognitive performance as such and to each other. In as far as the population is concerned, this study examined adolescents. However, it involved a much larger sample than the first study, which enables one to specify in more detail than the previous study the influence of development on the organization of actual cognitive abilities and self-awareness.

Several authors have studied the development of self-evaluation (Stipek, Recchia, & McClintic, 1992) and self-representation (Harter, 1998). These studies show that, with development, self-evaluation becomes more accurate and focused and self-representation becomes more differentiated and tuned with different aspects of cognitive and actual performance. However, these studies did not examine the development and condition of these aspects of self-awareness in connection to actual cognitive abilities. Some studies have indeed addressed together cognitive abilities and self-awareness. These studies showed that self-evaluation is a factor standing side by side with fluid intelligence (Stankov, 2000) and that metacognitive skillfulness is a general person-related characteristic that is not identical with intelligence and that independently contributes to learning (Veenman, Wilhelm, & Beishuizen, 2004). However, the design of these studies did not allow for a systematic and detailed specification of the relations between actual cognitive attainment and self-evaluation and self-representation. This is the aim of the present study.

2.1. Participants and tests

2.1.1. Participants

This study involved a total of 840 participants about equally sampled from each of the age groups 11 to 16. Specifically, 154, 145, 156, 172, 157, and 56 participants were included in the six age groups. All of the participants were Greeks leaving in the major area of Thessaloniki. Low (that is, working class families whose parents had received only primary education), lower middle (that is, families whose parents had received secondary education and they were mostly clerks or owners of small business), and upper middle class (that is, families where at least one parent had received university education and they were mostly professionals, such as doctors, lawyers, and university professors) were about equally represented in each age group but the last one, which involved only upper middle class adolescents. The two genders were about equally represented in each SES group of each age.

2.1.2. Cognitive tests

All of the domains mentioned above but creativity were addressed by two tasks clearly differing in difficulty. Specifically, the mathematical reasoning tasks addressed algebraic reasoning (i.e., specify x, given that $x=y+3$ and $y=1$; when is it true that $L+M+N=L+P+N$?). It can be seen that in the first of these tasks one of the unknowns in the main equation is fully specified. In the second equation the unknowns are specified in relation to each other. Thus, the second equation is more complex than the first. The responses to these tasks were scored as 0 (wrong) or 1 (correct responses).

The causal reasoning tasks addressed isolation of variables and integration of hypothesis with evidence. Specifically, the easy task tapped the isolation-of-variables ability in its simplest form. The participants were asked to use any of four different kinds of seed (wheat, lentils, beans, and pines) to test if growing in a shadowy place as compared to a sunny place affects the plant growth rate. To solve this problem, the participants must be able to understand that the same kind of seed has to be used across the two conditions of light intensity. In the difficult task three variables (plant, area, and frequency of irrigation) would have to be manipulated, each involving two levels. Obviously, this experiment is more complex than the previous because it requires to generate a total of 24 combinations. Performance on these tasks was scored as 0 (no, irrelevant, or entirely wrong responses), 1 (responses indicating an insufficient grasp of the isolation-of-variables scheme) or 2 (fully correct experiments and adequate explanations, indicating systematic application of the isolation-of-variables scheme).

The two social reasoning tasks addressed the ability to understand the motives and multiple perspectives underlying the interaction between several actors in a story. The first story was about two students, Kostas and Michalis, who concealed a third student's (Demetris') math notebook, making the math teacher scold Demetris and lower his grade. Subsequently, Michalis laughing "confessed" to Demetris, but Kostas apologised. Demetris answered them that he could no longer be Michalis' friend. Participants were asked to discuss the teacher's behavior and to express their opinion as to who was most at fault. The second story was similar in both spirit and content, but the relationships among the characters were more complex. Responses to these tasks were scored as 0 (responses indicating that participants understood only the surface characteristics and external behavior of the characters), 1 (responses indicating that participants considered several aspects of the actions involved, although without any general integration of actions, intentions, etc.), or 2 (responses indicating that participants attempted to form a balanced evaluation of a character's actions on the basis of the actions, intentions, etc. of all characters involved).

The two drawing tasks were taken from Case (1992) to address the ability to draw a scene involving various components related by various relations. In the first task, participants were asked to draw "a man and a woman standing hand-in-hand in the park, [whose] child is playing in front of them and a tree can be seen behind them." In the second task, participants were instructed as follows: "Draw three or more boats on the water at sunset. Some of the boats are close to you and others are further away. Try to draw the boats three-dimensionally. Using the criteria of Case (1992), performance on the two drawing tasks was scored as 0 (the elements – persons and objects – specified in the instructions are missing from the drawing or the drawing is very simplistic, or the elements are simply juxtaposed so that no organization can be discerned), 1 (the elements are present although they are given in outline and organized into a foreground, such that no three-dimensional organization may be discerned), 2 (the elements are clearly organized into an ensemble and there is clear differentiation between the foreground and the background and signs of the relations between elements).

Finally, the participants were given the symbol test from the Kit of Factor Reference Tests (Ekstrom, French, & Harman, 1976), which taps ideational fluency that is considered a measure of creativity. This test involves two parts. In part 1, participants were to draw up to five symbols for each of the following concepts: library, close the door, sad, rush, keep off the grass. In part 2, participants were asked to do the same for the following concepts: post office, open the window, happy, quiet, do not pick the flowers. Each of the two parts of the symbol test was scored according to the criteria described in Ekstrom et al. (1976).

2.1.3. Measures of self-awareness

Two kinds of self-awareness measures were taken in this study: self-evaluation of task-specific performance and perceived competence. Specifically, for self-evaluation, participants were asked to evaluate their performance on each of the eight tasks addressed to the four domains described above, that is mathematical, causal, social reasoning, and drawing. The participants were asked the following question: "How happy are you with the solution you gave? That is, how correct do you think your answer is?" and they were given a 7-point scale varying from 1 (it was completely wrong) to 7 (it was absolutely correct) to specify their evaluation. These subjective self-evaluation scores were then used, in combination with their corresponding scores reflecting the actual performance attained on each of the eight tasks, to generate the self-evaluation accuracy scores (SEA). The general rule guiding the formation of SEA was that persons were credited for self-evaluations that were consistent with performance on their corresponding tasks. SEA varied from 0 to 2. Specifically, in all but the algebraic reasoning tasks, a SEA of 0 was given to the following combinations of actual performance and self-evaluation scores, respectively: 0 and 4 or more; 1 and 3 or less; 2 and 3 or less. A SEA of 1 was given to the following combinations of actual performance and self-evaluation scores, respectively: 0 and 3; 1 and 6 or more; 2 and 4 or 5. Finally, a SEA of 2 was given to the following combinations of actual performance and self-evaluation scores, respectively: 0 and 1 or 2; 1 and 4 or 5; and 2 and 6 or 7. In the algebraic reasoning tasks, where performance was scored as 0 or 1, SEAs were formed as follows: 0 for a combination of 0 in performance and 4 or more in self-evaluation or 1 in performance and 2 or less in self-evaluation; 1 for a combination of 0 in performance and 3 in self-evaluation; 2 for a combination of 0 in performance and 2 or less in self-evaluation or 1 performance and 6 or more in self-evaluation.

Finally, we used an inventory to probe the person's general self-representation in regard to general cognitive processes and characteristics and specialized domains of reasoning, including the four domains addressed by the tasks presented above (Demetriou & Kazi, 2001). The inventory, which was shaped as a result of extended pilot investigations, involves statements describing a particular cognitive process or ability and the participant' task is to specify how much it applies to himself or herself in reference to a five-point scale (that is from 1 — not at all to 5 — very much). The items addressed to perceived general cognitive efficiency referred to processes such as learning, memory, and efficiency of processing, (e.g., "I learn fast," "I retain a lot of elements of what I hear," "I am fast in understanding things explained to me"). Statements addressed to *quantitative thought* referred to the person's facility in solving mathematical problems or applying mathematical knowledge to everyday problems (e.g., "I immediately solve everyday problems involving numbers"), the ability to induce or use mathematical rules (e.g., "I can easily derive the mathematical rules behind many specific examples"), and the facility to think in abstract symbols (e.g., "I prefer to think in terms of abstract mathematical symbols rather than specific notions"). Statements addressed to *causal thought* referred to hypothesis formation (e.g., "When something I use spoils, I usually make various guesses as to what might have caused it. I try to think of all the possible reasons that might have caused it"), experimentation (e.g., "To find out which of my guesses is correct, I proceed to methodically consider each time only the things my guess proposes"), and model construction ability (e.g., "From individual instances, I like deriving a general explanation for everything"). The statements addressed to social thought referred to the facility in understanding other's thoughts and feelings (e.g., "I understand easily the intentions of others before they express them"; "I am interested in understanding others' problems"). Finally, the statements addressed to drawing referred to ability to draw a man, a landscape, and a map (e.g., "I can draw a person very accurately," "I can paint a building as if it were a photograph").

For the sake of the analyses to be presented below, two mean scores were created for each domain, based on the results of exploratory factor analysis which revealed the stronger dimensions of self-representation in each domain.

The alpha reliability for the cognitive, the self-evaluation, and the self-representation inventory was .66, .77, and .83, respectively.

2.1.4. Procedure

Participants were tested in groups during school hours. Two experimenters were always present in the classroom to answer questions individually, if called by the participants. Batteries were presented in two booklets, one involving the cognitive tasks and related self-evaluation items and the other involving the self-representation inventory. The easy task was always presented before the difficult task within a domain. Presentation order of domains within the cognitive and self-evaluation battery was counterbalanced across participants. Also, the presentation of the cognitive and self-evaluation battery and the self-representation inventory was separated by about a week and their order was counterbalanced across participants.

2.2. Results and discussion

The design of this study provides the empirical basis to specify, first, how actual task-specific self-evaluation is related with cognitive ability, on the one hand, and perceived competence, on the other. Second, the large sample size of this study enables one to specify distinct profiles of cognitive ability and explore the relations between the various dimensions in each profile.

In the sake of the first aim, a series of confirmatory factor analysis and structural equations models were tested on both the whole sample of 840 participants and each of five age groups. All of these models were tested on the means of each pair of performance scores, each pair of SEA scores, and each pair of perceived competence scores. Therefore, there were five performance mean scores (that is, mathematical, causal, social reasoning, drawing, and creativity), four SEA mean scores (that is, mathematical, causal, social reasoning, and drawing), and five perceived competence mean scores (that is, mathematical, causal, social reasoning, drawing, and general processing efficiency). In the first model, shown in Fig. 2 (the correlations between the variables included in this model and their statistics are shown in Table A2 in the Appendix), each of these three sets of mean scores was regressed on a separate factor. Therefore, the first of these factors stands for general reasoning ability ($\mathbf{g}_{r}$), the second stands for the general ability for self-evaluation ($\mathbf{g}_{se}$), and the third for general perceived competence ($\mathbf{g}_{pc}$). These three first-order factors were regressed on a second-order factor that, ob-

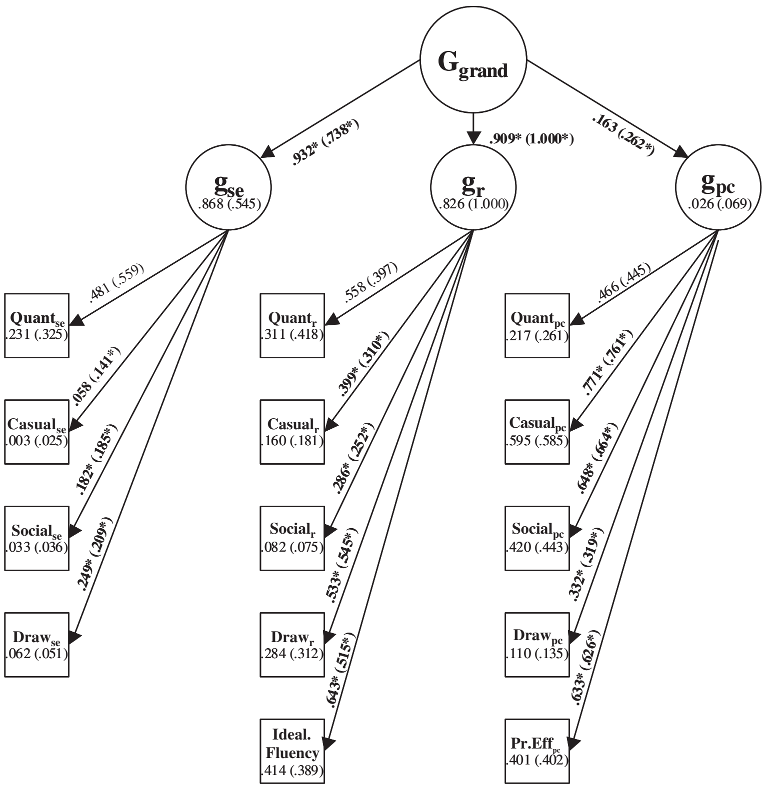

Fig. 2. The confirmatory factor analysis model for cognitive performance, self-evaluation, and self-representation of the cognitive processes examined in Study 2. Note: The first and the second coefficient in each pair represent relations before and after partialling out the effect of age. Free parameters are denoted by bold characters. Significant coefficients are denoted by asterisks. Numbers in squares and circles indicate variance accounted for.

viously, stands for $\mathbf{G}_{grand}$. The fit of this model was satisfactory, χ^2 (71) = 311.664, p = .000, CFI = .892, RMSEA = .062, 90% confidence interval = .056–.071 (χ^2 (71) = 270.407, p = .000, CFI = .925, RMSEA = .058, 90% confidence interval = .051–.065).

The general factor in this kind of models stands for the relations that interconnect the lower factors. To directly specify these relations, a structural equation model was tested where the second-order $\mathbf{G}_{grand}$ factor was abolished and the following relations between the first-order factors were built. First, the factor standing for SEA ($\mathbf{g}_{se}$) and the factor standing for perceived competence ($\mathbf{g}_{pc}$) were regressed on the general reasoning factor ($\mathbf{g}_r$). Moreover, the $\mathbf{g}_{pc}$ factor was regressed on the residual of the $\mathbf{g}_{se}$ factor. The fit of this model, which is illustrated in Fig. 3 was good, χ^2 (71) = 311.659, p = .000, CFI = .892, RMSEA = .064, 90% confidence interval = .056–.071 (χ^2 (71) = 270.348, p = .000, CFI = .924, RMSEA = .058, 90% confidence interval = .051–.065).

To test the possible effect of age on the factors and structural relations included in these two models, both of them were tested with the effect of age partialled out in the fashion used in Study 1. That is, all observed variables were regressed on age, in addition to the factor they are supposedly related to. The fit of these models (shown in parenthesis above) was good. Moreover, none of the relations between variables and factors or between factors was basically affected by this manipulation. Therefore, it is clear that the architecture and the relations captured by these models reflect the organization of the processes involved rather than developmental differences in their rate of change with age.

Special attention is drawn to the following aspects of the model. First, in the confirmatory factor analysis models, all three first-order factors were significantly related with the $\mathbf{G}_{grand}$ factor. It needs to be noted, however, that the relation of $\mathbf{g}_r$ and $\mathbf{g}_{se}$ with $\mathbf{G}_{grand}$ was very high in both models whereas the relation of $\mathbf{g}_{pc}$ with $\mathbf{G}_{grand}$ was very low. Second, in the structural models, the regression of $\mathbf{g}_{se}$ on the $\mathbf{g}_r$ was very high whereas the regression of $\mathbf{g}_{pc}$ on $\mathbf{g}_r$, although significant, was low. The regression of the $\mathbf{g}_{pc}$ on the residual of the $\mathbf{g}_{se}$ was practically null. It is clear, therefore, that the self-evaluation aspect of self-awareness is, together with reasoning, an integral part of $\mathbf{G}_{grand}$. The self-representation aspect of self-awareness only weakly partakes in this complex. In fact, the structural model suggests that self-evaluation is extensively shaped on the pattern of actual reasoning performance. Self-representation reflects, to some extent, actual reasoning ability but it is not related to self-evaluation as such.

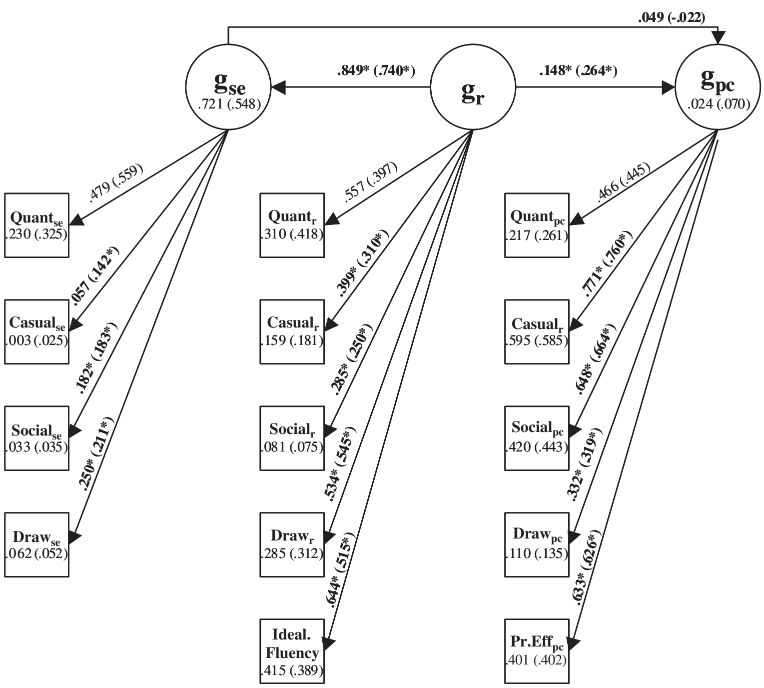

Fig. 3. The structural equation model for cognitive performance, self-evaluation, and self-representation of the cognitive processes examined in Study 2. Note: The first and second coefficient in each pair represent relations before and after partialling out the effect of age. Free parameters are denoted by bold characters. Significant coefficients are denoted by asterisks. Numbers in squares and circles indicate variance accounted for.

This pattern of relations suggests that self-monitoring and self-evaluation are firmly geared in the various domains of intellectual activity and they form a powerful dimension of $\mathbf{G}_{\text{grand}}$. However, the formation of perceived competence seems to reflect influences that go beyond one's state of sheer reasoning ability or on line self-evaluation.

The rather large number of participants involved in five of the six age groups enables one to zoom in on the relations between the various processes within the various age groups. In the sake of this aim the two models presented above were tested on five age groups in two multiple groups analysis. Specifically, in these models, each of the first four age groups was taken separately and the last two age groups were pulled together, due to the small number of participants in the group of the 16-year-olds. Both models were tested under the strict assumption that the relations of each of the observed variables with the factor it is related to are equal across the five groups. These equality constraints reflect the assumption that the various tasks and items measure their intended target process in the same way across groups. The relations between the factors were let to vary freely across the five groups in order to test if they change with age. The fit of both the confirmatory factor analysis model, χ^2 (399) = 753.676, p = .000, CFI = .85, RMSEAs = .033, 90% confidence interval = .029–.036, and the structural equations model, χ^2 (399) = 743.209, p = .000, CFI = .85, RMSEA = .032, 90% confidence interval = .028–.036, was satisfactory, especially if the large number of groups and between groups equality constraints are taken into account.

The coefficients reflecting the relations between the various factors generated by the two models are shown in Table 1. Inspection of these relations suggests some highly interesting conclusions about the emergence of self-awareness as a component of general intelligence. Specifically, inspection of the relations between each of the three process-specific factors with $\mathbf{G}_{\text{grand}}$ suggests that this factor starts to emerge as an integrative component only at the age of 13 years and beyond. It can be seen that at the age of 11 and 12 years only one process-specific factor ($\mathbf{g}_{\text{se}}$) is related with $\mathbf{G}_{\text{grand}}$. At the age of 14 years $\mathbf{g}_{\text{pc}}$ also enters the scene as its relation with $\mathbf{G}_{\text{grand}}$ becomes substantive and significant. However, up to this age, the relation of $\mathbf{g}_{\text{pc}}$ with $\mathbf{G}_{\text{grand}}$ is null. This relation, although low, becomes significant at the age of 14 years (.23) and moderate (.46) at the age of 15–16 years. The inspection of the structural relations between the process-specific factors revealed by the structural equations model further clarifies the coordination of the two aspects of self-awareness with actual performance and with each other. Specifically, it can be seen that the relation of $\mathbf{g}_{\text{se}}$ with $\mathbf{g}_{\text{r}}$ is very low and non significant at the age of 11 years and it then steadily and systematically increase until to approach unity at the age of 15–16 years (.97). Interestingly, the relations of $\mathbf{g}_{\text{pc}}$ with $\mathbf{g}_{\text{r}}$ and $\mathbf{g}_{\text{se}}$ do follow the same trend but with a considerable age lag. That is, the relation of $\mathbf{g}_{\text{pc}}$ with $\mathbf{g}_{\text{r}}$ remains circa 0 until the age of 13 years, it rises to moderate and significant at the age of 14 years (.34) and to high (.55) at the age of 15–16 years. In a similar fashion, the relation of $\mathbf{g}_{\text{pc}}$ with $\mathbf{g}_{\text{se}}$ remains circa 0 until the age of 13 years, it rises to moderate and significant at the age of 14 years (−.30) and to very high at the age of 15–16 years (−.80). However, these relations are negative.

Table 1
Relations between factors across age groups as revealed by multiple groups analyses

Factors	Relations of the process-specific factors with $\mathbf{G}_{\text{grand}}$ factors (confirmatory factor analysis)		Relations between process-specific factors (SEM model)	
	Age	$\mathbf{G}_{\text{grand}}$	$\mathbf{g}_{\text{r}}$	$\mathbf{g}_{\text{se}}$
$\mathbf{g}_{\text{r}}$	11	.162		
	12	.348		
	13	.800*		
	14	.438*		
	15–16	1.000*		
$\mathbf{G}_{\text{se}}$	11	1.000*	.184	
	12	.948*	.331*	
	13	1.000*	.776*	
	14	1.000*	.803*	
	15–16	.989*	.965*	
$\mathbf{G}_{\text{pc}}$	11	.009	−.004	.008
	12	.147	.060	.125
	13	−.031	.006	−.102
	14	.226*	.341*	−.302*
	15–16	.459*	.554*	−.802*

Note: N is 154, 145, 156, 172, and 213 in the five age groups, respectively. Asterisks indicate significant relations.

Taken together, these results suggest, first, that task-specific self-evaluation of performance is relatively accurate from the beginning of adolescence and it becomes increasingly accurate year after year so that by middle adolescence it is highly accurate. Second, the transformation of task-specific self-evaluations into an accurate general cognitive self-concept is slower and it starts to show up only from middle adolescence onwards. In fact, third, the negative relation of $\mathbf{g}_{\text{pc}}$ with $\mathbf{g}_{\text{se}}$ suggests that increasing accuracy in self-evaluation is associated with a downgrating of one's perceived competence. In other words, growth in reasoning ability and on-line self-evaluation results into a more conservative and, probably, more realistic cognitive self-concept. In other words, the self-representation of inferential processes at the beginning of a developmental phase is totally independent of the status of the actual inferential processes themselves or of the accuracy of task-specific self-evaluation. With development, however, it becomes coordinated with them, thereby becoming an integral part of general mental ability. This pattern of development is consistent with the developmental pattern of self-awareness revealed by the first study and it will be further discussed in the general discussion.

3. Study 3: processing potentials, reasoning, and self-representation

The first two studies addressed reasoning in various domains and various aspects of self-awareness related to reasoning in these domains. The present study is unique in that it involved measures of different aspects of processing efficiency (speed and control of processing) and capacity (phonological, visual, and executive working memory), in addition to reasoning in different domains and self-awareness about them. Therefore, this study can show how all three important dimensions of the human mind, namely processing efficiency and representational power, reasoning or psychometric *g*, and self-awareness, contribute to the formation of general intelligence. To our knowledge, no previous study has examined these relations. In other words, this study can show if a fundamental aspect of *g*, processing efficiency and representational power, that is supposed to be the engine of fluid intelligence, shares variance not only with inferential processes, that is now taken for granted by all students of intelligence, but also with self-awareness about them. It may be noted here that Jensen (2000) himself rejected the assumption advanced in a commentary by Demetriou (2000) that *g* has a subjective aspect. The present study can provide evidence directly related to this dispute.

3.1. Participants and tests

3.1.1. Participants

A total of 83 persons, about equally distributed among 11, 13, and 15-year-olds, were tested. All of these persons were students at the Experimental School of the Aristotle University of Thessaloniki and came from upper middle class families (where at least one of the parents received university education and they were mostly professionals, such as doctors, lawyers, and university professors). These persons participated in a three-year longitudinal study of the development of processing efficiency, working memory, and reasoning. This study is presented in Demetriou et al. (2002). The self-representation inventory was given only once at the third and last year of the study, when the students of the older cohort had already graduated.

3.1.2. Processing efficiency

A Stroop-like paradigm was employed to test speed and control of processing in three symbol systems: language, numeric, and figural. That is, for speed of processing in language, the participants were required to *read* single words written in the same ink color (e.g., RED in red ink, say red). For control of processing in language, the participants were required to *recognize the ink color* of color words denoting a different color (e.g., RED in green ink, say green). For speed of processing in the numerical system, the participants were required to recognize “*large*” number digits composed of the same digit (e.g., 7 composed of little 7s, say 7). For control of processing in this system, the participants were required to *recognize the small component digit* the large ones were composed of (e.g., 7 composed of 4s, say 4). For speed of processing in the figural system, the participants were required to recognize “*large*” geometrical figures composed of the same figures (e.g., a circle composed of circles, say circle). For control of processing in this system, the participants were required *to recognize the small component figures* composing the large figure (e.g., a circle composed of triangles, say triangle). There were two trials for each of the six conditions described above.

Attention is drawn to the fact that in all of the speed of processing tasks the participants were required to recognize the dominant attribute of the stimulus under conditions of facilitation because both the dominant and the weak attribute coincided. Therefore, reaction times to all three types of the compatible conditions described above indicate speed of processing, because participants must provide a familiar and well-practiced response to a perceptually dominant and familiar stimulus, under facilitating conditions. In the control of processing tasks, the two dimensions of the stimuli were different from each other and the participants were required to recognize the weak attribute under conditions of interference from the dominant attribute. Therefore, reaction times to the incompatible conditions indicate control of processing, because the participant must inhibit the tendency to react to the perceptually dominant but irrelevant stimuli, in order to encode and respond to the secondary but relevant stimuli (see Demetriou et al., 2002). For the purposes of the analyses to be described below, responses to all tasks addressed to speed of processing were pulled into one mean score and responses to all tasks addressed to control of processing were pulled into another mean score to represent these two dimensions of processing efficiency.

3.1.3. Working memory

Working memory was measured by tasks addressed to the three components specified by Baddeley (1990), that is, phonological and visuo/spatial short-term storage (STS) and the central executive (CE). The phonological STS was addressed by verbal and numerical tasks. Participants were presented with series of words or numbers (two to seven) and they were asked to recall them in the order of their presentation. There were two trials for each of the six levels of difficulty in each of these two symbol systems. The visuo/spatial STS was addressed by a task requiring to store shape, position, and orientation of geometric figures. Participants were presented a series of cards showing geometrical figures and were asked to fully reproduce them by choosing the appropriate figures among several ready-made cardboard geometrical figures that were identical in size and shape to the figures drawn on the target card. The CE was addressed by a set of tasks requiring one to combine either verbal with numerical or verbal with visual information. For example, in the verbal/numerical task participants were presented with verbal statements comprised of a subject, a verb, a numerical specification, and an object (e.g., "The man ate three apples," "The father bought two breads," "The boy has seven balls," etc.). Once all of the statements (from 2 to 7) in a set were presented, the participant was trained to recall either the subject or the numerical specification of all of the propositions in the set, as a response to the instruction WHO or HOW MANY, respectively. For the purposes of the analyses to be presented below, performance on the phonological, the visual, and the executive memory tasks were pulled together into three mean scores, each representing one of these three dimensions of working memory.

3.1.4. Reasoning tasks

The reasoning tasks addressed verbal, quantitative, and spatial reasoning. Verbal reasoning was addressed by verbal analogies and syllogistic reasoning tasks. There were four verbal analogies of the a : b :: c : d type, varying in difficulty in concern to the abstractness of the relations involved (e.g., ink : pen :: paint : ? The participant was asked to choose among three alternatives; color, brush, and paper, in the present item). There were four syllogistic reasoning tasks varying in difficulty in concern to the type of relations, such as implication and transitivity (e.g., "If animals live in a cage then they are not happy. The bird is happy ⇒? The participant was asked to choose among three alternatives; the bird lives in the cage, *the bird does not live in the cage*, none of the two, in the present item).

Quantitative reasoning was addressed by two types of tasks. First, there were six numerical analogies varying in difficulty according to the direction (increase or decrease) and the type of relation involved (i.e., double, triple, and one third; e.g., 6 : 12 :: 8 : ?, 6 : 4 :: 9 : ?). Second, there were four simple algebraic equations requiring to specify the arithmetic operations missing from them (e.g., (2 # 4) @ 2 = 6). Difficulty here was specified in reference to the number of missing operations.

Spatial reasoning was also addressed by two tasks. The first was a mental rotation task comprising six items. In this task, each item depicted a clock with one hand always pointing to the 12:00 position and the other pointing to either 12:15, 12:30, or 12:45. There was a geometrical figure (e.g., a triangle) drawn on the hand pointing to 12:00 position and the participant's task was to imagine that this hand is going to move until to sit on top of the other and draw (on the other hand) how the figure on the rotating hand would look after the rotation. Difficulty in this task was controlled in reference to two dimensions. That is, the complexity of the figures involved (some tasks involved a single geometrical figure – 3 and 5 – some other tasks involved a figure with diagonal lines drawn in it – 2 and 4 – and some involved two figures, the one embedded in the other—1 and 6) and the degree of rotation (that is, 45°, 90°, and 145°). The second task was a version of the classical Piagetian (Piaget & Inhelder, 1967) water-level task in which a picture of a half-full bottle was presented and the subject's task was to draw the line indicating the water level when the bottle was inclined first by 45° and then 90°.

All items in the cognitive battery were scored on a pass–fail basis (0 and 1). The mean scores used in the analyses below were computed by averaging over the items involved in each task.

Finally, the inventory used in the second study to probe the person's cognitive self-representation was also used in the present study. For the purposes of the present article, we used responses addressed to the three domains of thought represented in the study, that is, quantitative, verbal, and spatial reasoning. The statements addressed to *quantitative thought* have been described above. Statements addressed to verbal thought referred to logical reasoning (e.g., "I always try to draw logical conclusions that are justified by the evidence available") and logical cohesion (e.g., "When arguing, I try to use all evidence available in a systematic manner"). Statements addressed to *visuospatial* *thought* referred to visual memory (e.g., "I retain a very clear picture of things"), facility in thinking in images ("When I have to arrange things in a certain space, I first visualize what it will be like if I place them in certain way and then I arrange them in fact"), and spatial orientation (e.g., "I orient myself easily in a strange place if I am given instructions"). For the sake of the analyses to be presented below, two mean scores were created for each domain, based on the results of exploratory factor analysis which revealed the stronger dimensions of self-representation in each domain.

The alpha reliability for processing efficiency, working memory, reasoning, and self-representation tasks was .70, .70, .84, and .92, respectively.

3.1.5. Procedure

The processing efficiency, the working memory, and the reasoning tasks were individually addressed over separate days. The order of testing each of these domains was counterbalanced across participants. The self-representation inventory was addressed to the participants in groups on a separate day.

3.2. Results and discussion

To test the assumptions put forward above about the general architecture of the abilities represented in this study and specify the relations of the various main dimensions with g, a confirmatory factor model was fit to the 17 scores obtained from performance on the various tasks. Specifically, the mean score addressed to speed and the mean score addressed to control of processing were related to one factor, which stands for processing efficiency. The scores addressed to phonological, visuospatial, and executive memory were related to another factor, which stands for working memory. Each pair of scores addressed to a domain of reasoning was related to a separate factor. Therefore, there were three factors standing for performance on quantitative, verbal, and visuospatial reasoning. In a similar fashion, each pair of self-representation scores addressed to each of these three domains were regressed on a separate factor, which, therefore, stands for perceived competence in these domains. These first-order factors were regressed on three second-order factors. Specifically, the processing efficiency and the working memory factors were regressed on one factor that stands for general mental capacity ($\mathbf{g}_{\text{mc}}$). The three factors representing performance in the three domains were regressed on another second-order factor that stands for general reasoning ($\mathbf{g}_{\text{r}}$). The three factors representing self-representation of competence in the three domains were regressed on another second-order factor that stands for general perceived competence ($\mathbf{g}_{\text{pc}}$). Finally, the three second-order factors were regressed on a third-order factor that stands for $\mathbf{G}_{\text{grand}}$. The fit of this model, which is shown in Fig. 4 (the correlations between the variables included in this model and their statistics are shown in Table A3 in the Appendix), was excellent, χ^2 (108) = 122.228, p = .164, CFI = .960, RMSEA = .040, 90% confidence interval = .000–.071 (χ^2 (108) = 131.271, p = .063, CFI = .945, RMSEA = .051, 90% confidence interval = .000–.079). Attention is drawn to the relations between the three second-order factors and the g factor. They are all very high (all > .82), clearly suggesting that processing efficiency and capacity (the first factor), inferential and problem solving processes (the second factor), and self-representation about them (the third factor), are all complementary and very strong components of g.

To directly specify the relations between the second-order factors, a structural equation model was tested, in the fashion adopted in Study 2, where the third-order factor was abolished and the following relations between second- and first-order factors were built. First, the second-order factor standing for reasoning in the three domains ($\mathbf{g}_{\text{r}}$) and the second-order factor standing for general perceived competence ($\mathbf{g}_{\text{pc}}$) were regressed on the second-order factor standing for general mental capacity ($\mathbf{g}_{\text{mc}}$). These paths aim to specify the direct relations between the aspect of $\mathbf{G}_{\text{grand}}$ that define the processing potential available to the individual at a particular point in time, on the one hand, with its functional aspects that define inferential capabilities and self-awareness about them, on the other hand. Second, the $\mathbf{g}_{\text{pc}}$ factor was also regressed on the residual of the $\mathbf{g}_{\text{r}}$ factor to test how perceived cognitive competence is affected by inferential processes as such, on top of how they are affected by general processing potentials. Finally, each of the three domain-specific self-representation factors was regressed on the residual of its corresponding problem-solving factor, to test how, if at all, perceived competence in each particular domain represents the condition of the domain's problem solving powers, on top of whatever relations interconnect the second-order general factors.

The fit of this model (see Fig. 5) was also excellent, χ^2 (105) = 117.105, p = .191, CFI = .965, RMSEA = .038, 90% confidence interval = .000–.077 (χ^2 (105) = 124.210, p = .097, CFI = .954, RMSEA = .047, 90% confidence interval = .000–.070). It can be seen that both, the $\mathbf{g}_{\text{r}}$ (.90), and the $\mathbf{g}_{\text{pc}}$ factor (.76) where highly associated with the $\mathbf{g}_{\text{mc}}$. However, neither the relation between the residual of the $\mathbf{g}_{\text{r}}$ factor and the factor $\mathbf{g}_{\text{pc}}$

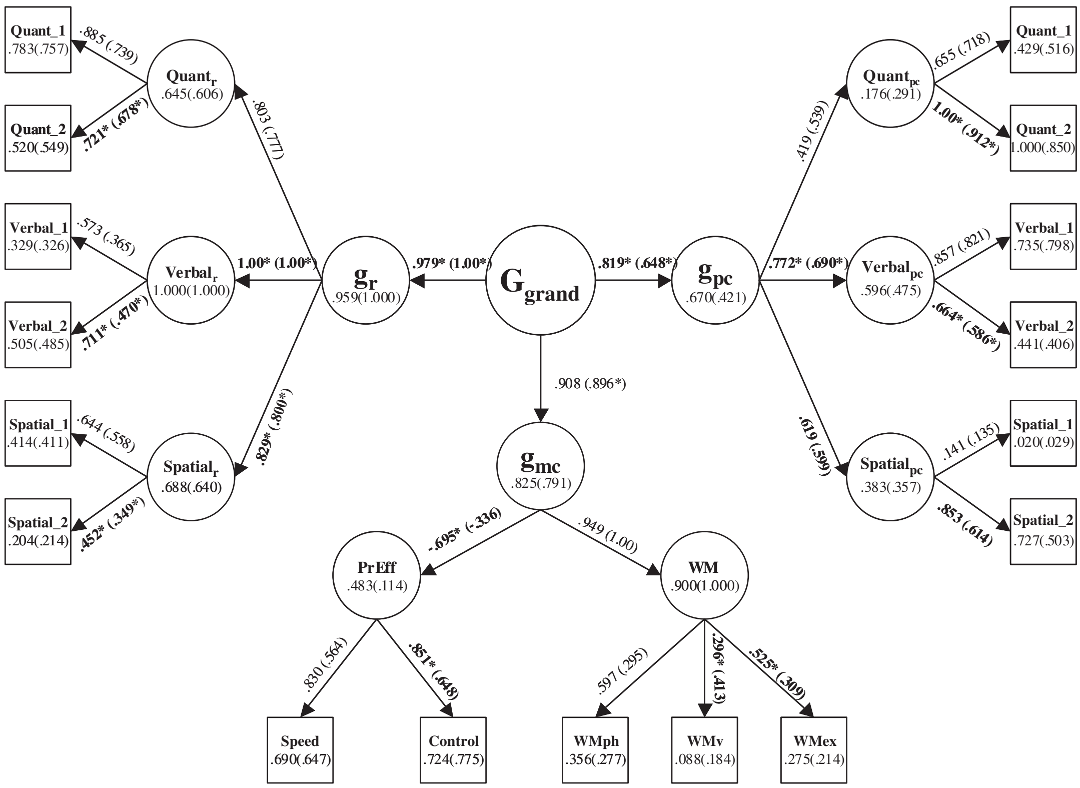

Fig. 4. The confirmatory factor analysis model for processing efficiency and capacity, reasoning, and self-representation of the cognitive processes examined in Study 3. Note: The first and the second coefficient in each pair represent relations before and after partialling out the effect of age. Free parameters are denoted by bold characters. Significant coefficients are denoted by asterisks. Numbers in squares and circles indicate variance accounted for.

(.19) nor the relations between the domain-specific perceived competence factors and their corresponding reasoning factors reached significance. It is clear, therefore, that inferential processes and perceived competence reflect extensively the state of processing potentials. The lack of direct relations between general perceived competence and general inferential processes or between the domains of perceived competence and their corresponding problem-solving domains indicates that the self-monitoring system forms a global self-representation of competence based on the actual power of mental efficiency. This is then used to derive self-representations about particular domains of problem solving.

To test the possible effect of age on the factors and structural relations included in this model, the two models above were tested with the effect of age partialled out in the fashion used in the other studies. That is, all observed variables were regressed on age, in addition to the factor they are supposedly related to. The fit of these models, which is shown in parenthesis next to the models ran before removing the effect of age, is good, suggesting that the general architecture and relations between factors is independent from developmental changes in the various processes. The inspection of the various coefficients, however, suggests clearly that development does have several effects on the strength of the various factors involved in the architecture and on the relations connecting these factors. Specifically, it should be noted, first, that the relations of the processing efficiency and the working memory measures with their corresponding factors dropped below significance while the relations of reasoning and perceived competence measures with their corresponding factors, although slightly reduced, did remain significant. In a similar fashion, of the various relations of the first-order factors with their corresponding second-order factor, only the processing efficiency and working memory factors with the general processing efficiency factor dropped below significance. Finally, the relations between the second order factors with the general factor did remain significant. In the second model, however, the relations between the $\mathbf{g}_r$ and the $\mathbf{g}_{pc}$ with the $\mathbf{g}_{mc}$ factor dropped below significance. Two conclusions are suggested by these findings. On the one hand, the general architecture of the

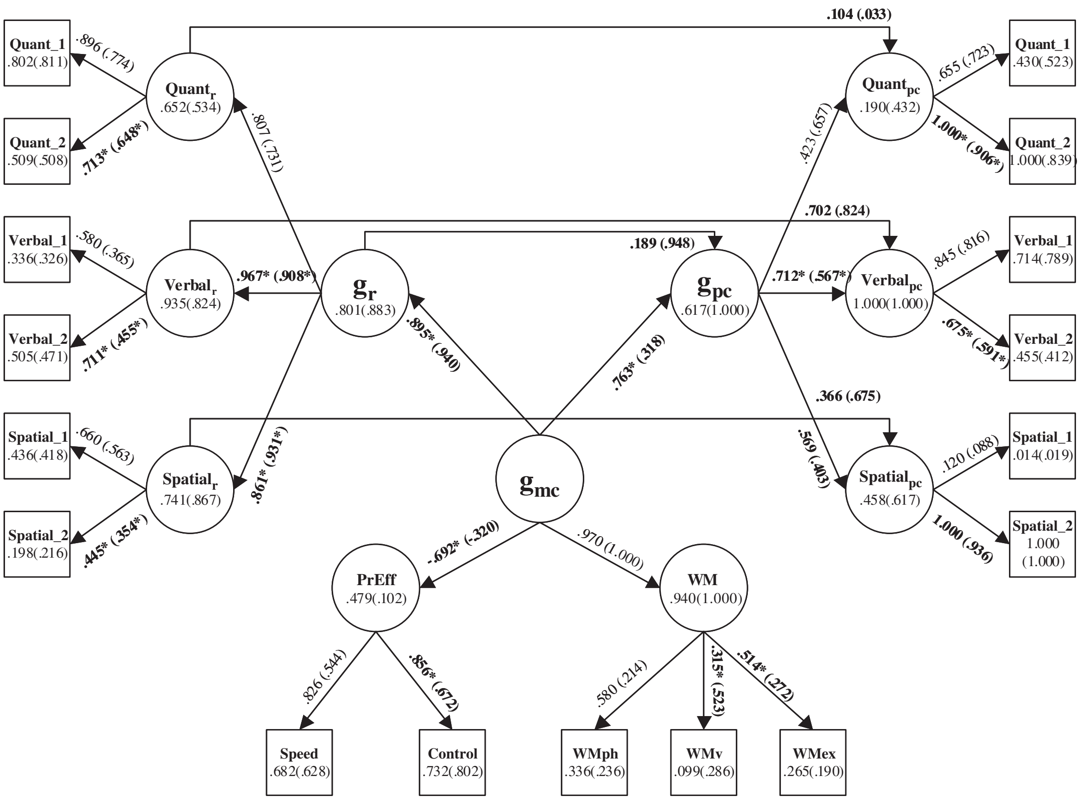

Fig. 5. The structural equation model showing relations between processing efficiency and capacity, reasoning, and self-representation of the cognitive processes examined in Study 3. Note: The first and second coefficient in each pair represent relations before and after partialling out the effect of age. Free parameters are denoted by bold characters. Significant coefficients are denoted by asterisks. Numbers in squares and circles indicate variance accounted for.

mind as reflected by these two models reflects genuine differences between the processes involved. Interestingly, the differences remain stable at both the level of the domains of reasoning and the level of self-representations about them. On the other hand, processing efficiency and its relations with the various domains of reasoning and self-representation are strongly age-dependent. This implies that processing efficiency reflects the operation of a general developmental factor that drives the development of reasoning in the various domains.

4. General discussion

The three studies presented here converge to three clear conclusions. First, *g* involves at least three types of processes: processing efficiency and representational capacity, inferential processes associated with various domains of understanding and problem solving, and self-awareness underlying self-monitoring, self-evaluation and self-representation. In fact, all three studies were clear in their implication that these three types of processes become, sooner or later, powerful components of *g*. The reader is reminded that the factors that represented these three broad types of processes were similarly related to the $\mathbf{G}_{\text{grant}}$ factor in all three studies, either across (Study 1 and 3) or in the older age groups (Study 2). This triarchic composition of *g* suggests that our interpretation of it must expand to include what has been lacking from our theories of intelligence. Specifically, at the beginning, *g*, defined as the eduction of relations and correlates (Spearman, 1904), was considered to reflect the state of inferential processes as the main dimension of individual differences in intelligence. Later on, this conception of *g* was differentiated into two complementary components, fluid and crystallized intelligence, that reflect the procedural and the declarative aspects and intellectual functioning, respectively (Cattell, 1971). This development opened the way for the connection of psychometric *g* with the constructs of processing efficiency and capacity that were formulated and tested in cognitive psychology. In fact, for many, inferential processes are dependent on, if they are not almost equivalent with, processing efficiency and capacity. The present study suggests that there is a third player in action. That is, self-awareness and the ensuing self-representations and self-concepts.

The second conclusion is concerned with the relations of self-awareness with the other two main players in *g*, that is processing efficiency and capacity and inferential processes. The three studies presented here suggest that self-awareness reflects these other players quite accurately. That is, it directly reflects the condition of processing efficiency and capacity and it is organized in domains that mirror the actual domains of reasoning. This is clearly suggested by the fact that the same domains are present in both the first-order factors of actual thought processes and the various aspects of self-awareness examined here. It is also to be noted that this organization of the mind at both the level of actual processes and the level of self-awareness about them is by and large independent of age. This was suggested by the fact that partialling out the effect of age did not exert any effect on the structure of processes and it only affected some of the relations between processes. The very fact that this picture holds for our first study which involved very young children strongly suggests that self-awareness is an integral part of the mind in general and *g* in particular from very early.

The third conclusion is concerned with development. Specifically, the stability of structure does not of course mean that there are no changes either in the functioning of the various systems or in their relations. The reader is reminded that partialling out the effect of age resulted in a serious weakening of the processing efficiency factor and of its relations with *g*. This finding strongly indicates that processing efficiency is the developmental driving force behind changes in *g* with growth. That is, changes in processing efficiency transform what is possible for the inferential and the self-awareness components of *g*. In other words, changes in processing efficiency open the way for the transformation of inferential and self-awareness processes but this transformation, when effected, always preserves the boundaries between domains and processes, as suggested by the fact that domain- and process-specific factors remain strong. What does this imply for the development of self-awareness? Simply stated, it implies that there is always some kind of self-awareness that is molded on the pattern of processes available at each phase of development. Thus, at different phases of development, self-awareness reflects the state, form, and dynamics of the processes that are attainable within each phase, weakly and imprecisely at the beginning of the phase and strongly and precisely at the end. Moreover, within each developmental phase, as shown by our first study, awareness moves from the surface or content-based characteristics of the abilities to be attained in a phase to their procedural and functional characteristics. In other words, the development of self-awareness seems to be a recycling process such that within each developmental phase it is weak and imprecise and content-centered at the beginning and stronger, more precise, and process centered at the end. This latter conclusion is strongly supported by the changes in the relations between factors revealed by our third study.

This pattern of changes provides a developmental role to self-awareness. That is, the grasp of awareness at each cycle of development becomes part and parcel of the mental material that will be reorganized into the new inferential structures of the next cycle. That is, reasoning develops as a result of a formalization process that constantly maps onto each other inferential patterns and action schemes within and across domains, thereby generating new management, validation, and reasoning patterns. The grasp of awareness of the processes characteristic of each cycle is a sine qua non condition for the transition to the next cycle because it enables the thinker to redescribe the processes and schemes of the present level into a higher, more efficient and flexible level of representation (Karmiloff-Smith, 1992). In line with the model sketched here, Moshman (1990) has advanced a model of the development of reasoning, which posits that increasing awareness of the inferential processes is the crucial factor for the transition to higher levels of reasoning.

Where does this intertwining of processing efficiency, domain-specific inferential processes and self-awareness come from? We suggest that the key to this connection is a mechanism where all of these three aspects of the human mind converge. This is a directive-executive function (DEF) that is responsible for setting and pursuing mental and behavioral goals until they are attained. DEF involves, by definition, an active storage where the current goals are represented, a planning function that proactively constructs a road map of the steps to be made in the sake of the goal, a control function that can register divergences between the goal and the current state and effect corrective action, and an evaluation function that enables the mind to finalize a course of (mental or actual) action. DEF is, in itself, domain-free. However, it is always applied on some aspects of the environment that are represented and processed by some mental processes that are relevant to these aspects. As a result, its functioning is always constrained by the current processing potentials of the system, such as speed of operation and representational capacity, and the domain of thought activated. Self-awareness is an integral part of DEF, because the very process of setting mental goals, planning their attainment, monitoring action vis-à-vis both the goals and the plans, and regulating real or mental action requires a system that can remember and review and therefore know itself. Therefore, conscious awareness and all ensuing functions, such as a self-concept (that is, awareness of one's own mental characteristics, functions, and mental states) and a theory of mind (that is, awareness of others' mental functions and states) are part of the very construction of the system. It is highly desirable to test and empirically substantiate these assumptions about the intertwining and development of the various processes by longitudinal, preferably microgenetic, research. This kind of research would be able to directly highlight how changes in each of the processes may cause changes in all of the other processes.

In conclusion, the three studies summarized here showed clearly that the mind involves both, very powerful domain-specific systems of mental operations and skills and very powerful domain-general systems that constrain ($\mathbf{g}_{mc}$), monitor, evaluate, ($\mathbf{g}_{se}$), and represent ($\mathbf{g}_{pc}$) the functioning of the domain-specific systems, and provide them meaning-making and inferential systems that can be applied on the domain of relations concerned ($\mathbf{g}_{r}$). These three types of general processes are always present, in proportions that vary with conditions and the developmental and learning history of the individual. It should be stressed, however, that domain-specific processes and constraints are never by-passed by constructions in *g*, however powerful they are, because the domains are the interface through which the mind interleaves with the different realms of the world. In other words, general processes may be everywhere but they can never function alone and specialized domains involve general processes as part of their construction and they need them for their efficient functioning and development.

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Appendix A

Table A1
Correlations, means, and standard deviations for the variables included in the models tested in Study 1

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. Count	1.000														
2. Arithmetic	.722	1.000													
3. Vehicles	.450	.554	1.000												
4. Geometric objects	.516	.636	.513	1.000											
5. Puzzle	.437	.482	.337	.362	1.000										
6. Geometric figures	.658	.776	.492	.489	.488	1.000									
7. Class vs. class (1)	.561	.566	.417	.422	.421	.486	1.000								
8. Class vs. class (2)	.422	.573	.464	.515	.389	.470	.669	1.000							
9. Count vs. count (1)	.299	.387	.368	.323	.303	.304	.552	.606	1.000						
10. Count vs. count (2)	.408	.548	.508	.487	.389	.397	.754	.698	.589	1.000					
11. Puzzle vs. puzzle (1)	.401	.469	.476	.460	.350	.328	.582	.626	.618	.598	1.000				
12. Puzzle vs. puzzle (2)	.386	.504	.425	.466	.395	.374	.590	.668	.637	.669	.691	1.000			
13. Class vs. count	.305	.526	.412	.437	.373	.426	.599	.711	.569	.642	.597	.665	1.000		
14. Class vs. puzzle	.409	.616	.420	.468	.531	.438	.626	.650	.519	.703	.597	.784	.700	1.000	
15. Count vs. puzzle	.366	.544	.488	.451	.574	.484	.603	.661	.474	.655	.609	.687	.655	.825	1.000
16. Age	.757	.843	.534	.643	.469	.767	.529	.548	.370	.523	.413	.466	.463	.581	.498
Mean	9.440	3.230	4.100	4.080	5.580	4.820	1.690	1.630	1.820	1.640	1.710	1.670	1.820	1.830	1.790
Standard deviation	3.828	1.483	3.314	4.521	2.749	2.556	1.061	1.089	1.077	1.059	.998	.900	1.167	1.138	1.113

Table A2
Correlations, means, and standard deviations for the variables included in the models tested in Study 2

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. Quant_r	1.000													
2. Causal_r	.317	1.000												

Table A2 (*continued*)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
3. $Social_r$	.177	.092	1.000											
4. $Draw_r$	.213	.203	.152	1.000										
5. Ideational fluency	.350	.271	.169	.422	1.000									
6. $Quant_{se}$	.380	.167	.114	.184	.168	1.000								
7. $Causal_{se}$	.000	.040	.019	.011	−.037	.112	1.000							
8. $Social_{se}$	.083	.048	.668	.045	.090	.105	.089	1.000						
9. $Draw_{se}$	.071	.078	.085	.510	.221	.072	.012	.023	1.000					
10. $Quant_{pc}$	−.096	−.032	.044	−.020	−.040	.032	−.053	.064	−.044	1.000				
11. $Causal_{pc}$	.006	.015	.017	.084	.091	.089	−.029	.067	−.016	.344	1.000			
12. $Social_{pc}$	.065	.041	.029	.124	.142	.068	−.034	.069	−.020	.222	.523	1.000		
13. $Draw_{pc}$	−.134	−.090	−.066	.173	.024	−.067	−.127	−.009	.073	.254	.228	.267	1.000	
14. Pr. $eff._{pc}$	.013	.029	.064	.105	.054	.066	−.068	.062	−.010	.384	.483	.389	.158	1.000
15. Age	.510	.292	.109	.122	.352	.114	−.069	.043	.085	−.251	−.079	.040	−.182	−.100
Mean	.555	.121	.808	.923	1.391	.649	.807	.920	1.096	4.545	5.125	4.924	3.870	5.452
Standard deviation	.371	.320	.671	.563	.594	.354	.590	.649	.619	1.346	.984	1.082	1.529	.933

Table A3

Correlations, means, and standard deviations for the variables included in the models tested in Study 3 on the whole sample

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1. Speed	1.000																
2. Control	.707	1.000															
3. WMph	−.307	−.321	1.000														
4. WMv	−.070	−.220	−.010	1.000													
5. Wmex	−.294	−.339	.392	.166	1.000												
6. $Quant_r$ (1)	−.342	−.339	.332	.367	.327	1.000											
7. $Quant_r$ (2)	−.254	−.219	.229	.204	.222	.638	1.000										
8. $Verbal_r$ (1)	−.432	−.339	.241	.198	.197	.381	.381	1.000									
9. $Verbal_r$ (2)	−.397	−.357	.361	.217	.213	.532	.449	.376	1.000								
10. $Spatial_r$ (1)	−.295	−.349	.431	.347	.229	.346	.193	.382	.313	1.000							
11. $Spatial_r$ (2)	−.099	−.159	−.022	.225	.135	.390	.348	.263	.213	.291	1.000						
12. $Verbal_{pc}$ (1)	−.247	−.234	.416	.023	.198	.301	.307	.318	.425	.262	.073	1.000					
13. $Verbal_{pc}$ (2)	−.293	−.291	.320	.123	.222	.212	.257	.325	.364	.149	.202	.569	1.000				
14. $Quant_{pc}$ (1)	−.046	−.088	−.006	.047	.059	.202	.134	.009	.129	.247	.201	.219	.083	1.000			
15. $Quant_{pc}$ (2)	−.018	−.121	.097	−.011	.097	.245	.248	.068	.204	.283	.257	.360	.167	.655	1.000		
16. $Spatial_{pc}$ (1)	.035	.006	−.028	.189	.017	−.016	−.124	.024	−.071	.128	.075	.109	.026	.131	.152	1.000	
17. $Spatial_{pc}$ (2)	−.309	−.272	.265	.099	.184	.334	.272	.160	.424	.126	.148	.323	.211	.108	.217	.120	1.000
18. Age	−.576	−.593	.436	.112	.341	.461	.296	.439	.514	.319	.303	.351	.251	.003	.135	.107	.351
Means	.509	.616	4.602	3.434	3.365	.731	.525	.554	.524	.774	.886	3.691	3.558	4.076	4.611	5.193	4.855
Standard deviation	.080	.104	.619	.837	.573	.243	.237	.187	.252	.205	.251	.934	.915	1.825	1.502	1.287	1.433

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