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Heuristic and analytic processing: Age trends and associations with cognitive ability and cognitive styles

Judite V. Kokis, [a] Robyn Macpherson, [a] Maggie E. Toplak, [b] Richard F. West, [c] and Keith E. Stanovich [a,*]

[a] *University of Toronto, Ont., Canada M5S 1V6*
[b] *Brain and Behaviour Research Program, The Hospital for Sick Children, Ont., Canada M5G 1X8*
[c] *James Madison University, Harrisonburg, Virginia, 22807, USA*

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Abstract

Developmental and individual differences in the tendency to favor analytic responses over heuristic responses were examined in children of two different ages (10- and 11-year-olds versus 13-year-olds), and of widely varying cognitive ability. Three tasks were examined that all required analytic processing to override heuristic processing: inductive reasoning, deductive reasoning under conditions of belief bias, and probabilistic reasoning. Significant increases in analytic responding with development were observed on the first two tasks. Cognitive ability was associated with analytic responding on all three tasks. Cognitive style measures such as actively open-minded thinking and need for cognition explained variance in analytic responding on the tasks after variance shared with cognitive ability had been controlled. The implications for dual-process theories of cognition and cognitive development are discussed.

* Corresponding author.
E-mail address: Kstanovich@oise.utoronto.ca (K.E. Stanovich).

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An influential framework for recent work on thinking and reasoning in cognitive science has been the so-called dual-process framework (Epstein, 1994; Evans, 1984, 1996; Evans & Over, 1996; Sloman, 1996; Stanovich, 1999). Dual-process theories of thinking posit the existence of two different cognitive architectures that have somewhat different functions, strengths, and weaknesses.

There are many such dual-process models, and most share some basic family resemblances (for detailed discussions, see Brainerd & Reyna, 2001; Chaiken & Trope, 1999; Epstein, 1994; Evans & Over, 1996; Nisbett, Peng, Choi, & Norenzayan, 2001; Pollock, 1995; Sloman, 1996; Smith & DeCoster, 2000). In such theories, one of the systems is characterized as automatic, heuristic-based, and relatively undemanding of computational capacity. Thus, this system (often termed the heuristic system) conjoins properties of automaticity, modularity, and heuristic processing as these constructs have been variously discussed in the literature. The heuristic system[1] responds automatically and rapidly to the holistic properties of stimuli. It is biased toward judgments based on overall similarity to stored prototypes (see Sloman, 1996).

The other system (often termed the analytic system) conjoins the various characteristics that have been viewed as typifying controlled processing—serial, rule-based, language-biased, and computationally expensive cognition. This system encompasses the processes of analytic intelligence that have traditionally been studied by information processing theorists trying to reveal the computational components underlying intelligence. The analytic system processes information in terms of the internal structure of stimuli and uses systematic rules that operate on the components of stimuli, rather than processing in terms of holistic representations.

In terms of the common distinction in cognitive science between the biological level, algorithmic level, and intentional level of analysis (see Anderson, 1990; Dennett, 1987; Marr, 1982; Stanovich, 1999), the properties discussed so far have been the so-called algorithmic-level properties. At the intentional level of analysis, the goal structure of the heuristic system is assumed to have been determined largely by evolutionary adaptation, whereas the goal structure of the analytic system is assumed to be more flexible and responsive to environmental experience. Thus, it is assumed in dual-process theories that the heuristic system is an older evolutionary product (Evans & Over, 1996; Mithen, 1996; Reber, 1992, 1993). A corollary of this assumption is that the heuristic system is also ontogenetically earlier

[1] The term heuristic *system* is a misnomer in a sense, since it implies a single cognitive system. In fact, we intend the term to refer to a (probably large) *set* of systems in the brain—partially encapsulated modules in some views—that operate autonomously in response to their own triggering stimuli, and not under the control of a central processing structure (see Anderson, 1998; Baron-Cohen, 1998; Cosmides & Tooby, 1994; Fodor, 1983; Hirschfeld & Gelman, 1994; Navon, 1989; Pinker, 1997; Samuels, 1998).

developing—and that the analytic system is both a phylogenetically and ontogenetically later developing system. Additionally, the analytic system is more strongly associated with individual differences in computational capacity (indirectly indicated by general tests of cognitive ability—and more directly tapped by indicators of working memory, see Engle, Tuholski, Laughlin, & Conway, 1999; Stanovich & West, 2000). One important function of the analytic system is to serve as a mechanism that can override inappropriately overgeneralized responses generated by the heuristic system (Pollock, 1995; Stanovich, 1999)—hence the tendency to link aspects of analytic processing with notions of inhibitory control (e.g., Barkley, 1998; Dempster & Corkill, 1999; Harnishfeger & Bjorklund, 1994; Norman & Shallice, 1986) and with metacognitive reasoning (e.g., Moshman, 1994).

Despite the theoretical fruitfulness of dual-process theories, empirical data with respect to its predictions regarding individual differences and development remain mixed. In the present investigation, we attempt a converging test of both the developmental and individual difference predictions. Dual-process theories are fairly uniform in their predictions in both domains[2] (Klaczynski, 2001a; Stanovich, 1999; Stanovich & West, 2000). The tendency for analytic processing to override heuristic processing is expected to increase with development, and it is also expected to be positively associated with differences in computational capacity among individuals of the same age.

The latter association has been observed in the literature in several studies, but not in others. For example, the representativeness heuristic that causes the famous conjunction error revealed by Kahneman and Tversky (1983) in the so-called Linda problem is disproportionately suppressed for adults of higher intelligence (Stanovich & West, 1998b); the use of the matching heuristic that leads to errors on Wason's (1966) four-card selection task (see Manktelow, 1999) decreases with increasing intelligence (Dominowski & Dallob, 1991; Stanovich & West, 1998a; Valentine, 1975); and the analytic use of base-rate information and information about the alternative hypothesis increases with increasing intelligence (Jepson, Krantz, & Nisbett, 1983; Stanovich & West, 1999). Other examples abound. For example, the heuristic tendency to apply the differential gain/loss function of prospect theory (Kahneman & Tversky, 1979)—a tendency that leads to a framing effect in the well-known Asian Disease problem (Tversky & Kahneman, 1981)—is less strong in more cognitively flexible individuals, thus leading to fewer framing effects (Chatterjee, Heath, Milberg, & France, 2000; Smith & Levin, 1996; Stanovich & West, 1998b, 1999). Finally, on a host of tasks where participants must avoid the natural tendency to contextualize problems, individuals of higher intelligence are more able to override

[2] The predictions of fuzzy-trace theory can become more complex than this because both verbatim processing of precise memory information and the intuitive processing of gist both improve with age in that theory (see Brainerd & Reyna, 2001).

interfering world and personal knowledge (Sá, West, & Stanovich, 1999; Stanovich, 1999; Stanovich & West, 1997, 2000).

Despite this consistent set of findings, other studies—particularly those deriving from the informal reasoning literature—have failed to observe a relation between optimal responding and cognitive ability. For example, Kardash and Scholes (1996) found that the tendency to properly draw inconclusive inferences from mixed evidence was not related to verbal ability because a vocabulary measure was essentially unrelated to evidence evaluation. Likewise, Klaczynski (1997) (see also Klaczynski & Gordon, 1996; Klaczynski, Gordon, & Fauth, 1997) found that the degree to which adolescents criticized belief-inconsistent evidence more than belief-consistent evidence was unrelated to cognitive ability (see also, Perkins, Farady, & Bushey, 1991).

As with the research on individual differences, research that has attempted to extend the heuristics and biases tasks studied in the adult literature (e.g., Evans, 1989; Kahneman, Slovic, & Tversky, 1982; Manktelow, 1999; Stanovich, 1999) to children has not always revealed the expected developmental trends. Dual-process theories share with many developmental theories (e.g., Case, 1985, 1991; Inhelder & Piaget, 1958; Piaget, 1926, 1972) the assumption that children's reasoning becomes more analytical, complex, and abstract with age, and there have been some developmental studies that have supported this view (Bara, Bucciarelli, & Johnson-Laird, 1995; Byrnes & Overton, 1986; Janveau-Brennan & Markovits, 1999; Klahr, Fay, & Dunbar, 1993; Kuhn & Pearsall, 2000; Markovits & Vachon, 1989; Moshman & Franks, 1986; Overton, Byrnes, & O'Brien, 1985). Nevertheless, the expected converse trend—that heuristic use would decrease with age (due to a higher probability of analytic override)—has not always been born out. Reyna and Ellis (1994) found that certain framing effects in risky choice situations increased with age instead of decreased as would be expected. In certain conditions of experiments examining the use of base-rate information versus indicant information (the classic paradigm used to study base-rate neglect, see Kahneman & Tversky, 1973), Jacobs and Potenza (1991) and Davidson (1995) found that base-rate usage sometimes decreased with age and indicant usage increased. This pattern is the opposite of what would be expected if the representativeness heuristic were being overridden with greater frequency by older children.

Finally, work by Klaczynski (2001a,b) on a variety of heuristics and biases tasks has produced mixed trends. He found (Klaczynski, 2001b) that the denominator neglect that accounts for the ratio-bias phenomenon discovered by Epstein (1994; Denes-Raj & Epstein, 1994; Kirkpatrick & Epstein, 1992) was constant from early adolescence to young adulthood, but there was some developmental increase in the normatively correct processing that prevents the nonconsequentialist honoring of past investment that traditionally defines the sunk cost fallacy (see Arkes, 1996). However, in another study, Klaczynski (2001a) did find considerable evidence for a decrease in heuristic responding between 12 and 16 years of age across a variety of tasks. For example, the representativeness-based conjunction fallacy decreased with age, as did measures of outcome bias (Baron & Hershey, 1988). In summary, the developmental literature is mixed in its support for the key prediction of dual-process theories.

It is possible that the conflicting results are best accommodated by a more complex set of dual-process assumptions than are typically assumed. Fuzzy-trace theory (Brainerd & Reyna, 2001; Reyna & Brainerd, 1995) may provide a dual-process conception that contains the requisite complexity. Rather than emphasize a unidirectional development trend toward more analytic system override with age, fuzzy-trace theory emphasizes that both precision-based analytic processing and heuristic-based gist processing increases with development. Because, on this theory, reasoning tasks have a greater tendency than memory tasks to be based on gist processing, reasoning tasks can sometimes produce developmental trends that contradict the more standard view which emphasizes developmental increases in analytic override tendencies.[3]

An alternative way of dealing with the conflicting results is to inquire whether task factors might be responsible. In at least some of the cases of these conflicting results, we think that stimulus factors—particularly how adult heuristics and biases tasks are adapted for use by children—may explain some of the discrepancies. For example, in the base-rate studies by Davidson (1995) and Jacobs and Potenza (1991), the discrepancy can be explained by examining the details of the studies. In these studies, indicant information of weak diagnosticity is pitted against more reliable statistical base-rate information. Use of the representativeness heuristic presumably triggers reliance on the less reliable indicant information. However, the diagnosticity of the indicant information in these studies is dependent on knowledge of a stereotype (Billy likes dancing and is thus more likely to prefer cooking to football)—and stereotype knowledge increases with age. Since younger children lack knowledge of many social stereotypes, they may seem to be using base-rate information more because the indicant information is unavailable to them. In contrast to performance on the so-called "social" condition, base-rate use does not decrease with age in the so-called "object" condition of Jacobs and Potenza (1991). The reason is that in the object condition the indicant information is not dependent on knowledge of a stereotype.

[3] The dual-process view adopted here shares with fuzzy-trace theory a rejection of what Brainerd and Reyna (2001) call the "illusion of replacement" (p. 52)—the idea that analytic thought *replaces* heuristic thought. Instead, the modal dual-process notion adopted here (a synthesis of many earlier views, see Stanovich, 1999; Stanovich & West, 2000) shares with fuzzy-trace theory the assumption that both heuristic and analytic processing modes are available at all points in development, at least after infancy.

Whether such stimulus factors can explain all of the seemingly paradoxical developmental increases in heuristic responding is an open question (see, for example, Klaczynski & Narasimham, 1998; Markovits & Dumas, 1999). In the present investigation, we have adopted the strategy of sampling tasks widely from domains in the reasoning and decision making literature and carrying out careful adaptations of the tasks into versions appropriate for children. Additionally, we examined developmental differences and individual differences within a single study. Within our developmental comparison we also assured a wide range of cognitive ability by oversampling children of high intelligence. In dual-process theories, age is an indirect measure of the variable that intelligence tests measure directly (the computational capacity of the analytic system). Thus, we expected that cognitive ability would probably prove a more potent predictor of heuristic/analytic processing than age. Indeed, the rather loose connection between age and cognitive ability among children may have contributed to the less than clear developmental trends in the literature.

We carefully adapted materials from adult studies in three domains that had been explored by previous investigators: inductive reasoning (Jacobs & Potenza, 1991; Klaczynski, 2001a; Stanovich & West, 1998c), deductive reasoning with a belief bias component that required analytic processing to override heuristic processing (Markovits & Nantel, 1989; Stanovich & West, 1997); and probabilistic reasoning (Denes-Raj & Epstein, 1994; Klaczynski, 2001b). The present study also examined the relations between heuristic/analytic responding and a variety of cognitive styles including: styles of epistemic regulation (through an actively open-minded thinking questionnaire), styles of cognitive regulation (need for cognition), and styles of response regulation (reflectivity/impulsivity).

We conceptualize cognitive/thinking styles as intentional-level psychological constructs (Stanovich, 1999; Stanovich & West, 1997, 2000) as opposed to cognitive ability that is viewed as an algorithmic-level construct. In cognitive science, the algorithmic level of cognitive theory is concerned with the computational processes necessary to carry out a task; whereas the intentional level refers to the specification of the goals of the system's computations (*what* the system is attempting to compute and *why*). Omnibus measures of cognitive ability such as intelligence tests are best understood as indexing individual differences in the efficiency of processing at the algorithmic level. In contrast, cognitive styles as traditionally studied in psychology (e.g., Kardash & Scholes, 1996; Klaczynski, 2000; Schommer, 1994; Stanovich & West, 1997; Sternberg, 1997) index individual differences at the intentional level of analysis. They describe the individual's goals and epistemic values (Dole & Sinatra, 1998; Kuhn, 2001; Sá et al., 1999)—and they are indexing broad tendencies of pragmatic and epistemic self-regulation.

Investigation of cognitive styles becomes particularly interesting in the context of measurements of cognitive ability. Our investigation was designed to determine whether performance on this particular array of rational thinking tasks is determined only by computational limitations at the algorithmic level of analysis. Perhaps variation in cognitive styles at an intentional level of analysis also partially determine the level of analytic responding in the inductive, deductive, and probabilistic domains—independent of differences in cognitive ability.

Method

Participants

The participants were 108 students (48 females and 60 males) in grades 5, 6, and 8, placed in general and gifted classes in one urban school. The school serves primarily a lower-middle to middle class population base. The school also contains a self-contained gifted program for grades 5–8. Four participants from the original sample of 112 were eliminated, two because they were recent immigrants who had been doing schoolwork in English for less than two years and two who had pro-rated IQ scores of less than 80. All grade 5, 6, and 8 students in the school were invited to participate in the study and given an information/permission form to take home for their parents to read. The grade 5 and 6 students were collapsed into one group and served as the developmental contrast with grade 8 students. The participants were divided into four groups distinguished by differences in grade (5/6 versus 8) and program (general versus gifted). Table 1 displays the mean ages of each of the four groups.

Pro-rated IQ and cognitive ability

Participants completed a short form of the Wechsler Intelligence Scale for Children-III (WISC-III, Wechsler, 1991). The short form consisted of the Vocabulary and the Block Design subtests. This particular dyad of subtests is reported to have the highest reliability and validity coefficients of the various two subtest short forms of the WISC-III (Sattler, 1992). These two subtests were prorated to give an estimated Full-scale IQ score using formulas in Sattler (1992).

An IQ score is an age-relativized measure. Models of computational capacity in the cognitive science literature concern *absolute* computational capacity. Thus, an additional measure of absolute cognitive ability was created. For this variable, the raw scores on the subtests (Vocabulary and Block Design) were standardized and summed to form a measure of absolute cognitive ability with no correction for age.

Table 1 displays the mean pro-rated IQ scores of each group. A 2 (program: general versus gifted) $\times$ 2 (grade: 5/6 vs 8) ANOVA on the pro-rated IQs indicated that there was a significant main effect of program,

Table 1
Mean age, pro-rated IQ, and cognitive ability for each of the four participant groups

	Grade 5/6		Grade 8	
Program:	General ($n = 31$) M (SD)	Gifted ($n = 26$) M (SD)	General ($n = 26$) M (SD)	Gifted ($n = 25$) M (SD)
Age (months)	132.5 (9.5)	127.5 (8.5)	160.7 (3.9)	160.9 (3.1)
Pro-rated I.Q	94.4 (11.2)	128.8 (10.4)	96.7 (14.4)	121.3 (10.1)
Cognitive ability	−1.91 (1.14)	0.68 (0.92)	−0.29 (1.21)	1.97 (0.60)

Note. Cognitive ability is the sum of the z-scores of WISC-III Block Design and Vocabulary subtests.

$F(1, 104) = 172.63$, $p < .001$, but no significant main effect of grade. The interaction of grade by program was significant, $F(1, 104) = 4.72$, $p < .05$. The interaction occurred because the program difference in IQ was larger in the grade 5/6 group than in the grade 8 group (35 points versus 25 points).

Table 1 also displays the mean cognitive ability scores of each group. A 2 (program: general versus gifted) × 2 (grade: 5/6 versus 8) ANOVA on the cognitive ability scores indicated that there was a significant main effect of program, $F(1, 104) = 154.35$, $p < .001$, and a significant main effect of grade, $F(1, 104) = 55.62$, $p < .001$, but no significant interaction. Grade 8 children had higher cognitive ability scores than grade 5/6 children, and children in the gifted program had higher cognitive ability scores than children in the general program. In fact, the grade 5/6 children in the gifted program had higher cognitive ability scores than the grade 8 children in the general program.

Tasks

Inductive reasoning task

The inductive reasoning problems were taken from Fong, Krantz, and Nisbett (1986) (see also Jepson et al., 1983) and adapted for use by children. Students read 15 reasoning problems about everyday matters. Seven of the problems involved the accurate use of base-rate information only. Responses for all four groups were close to ceiling on these problems (73.1% of the sample got all seven correct) and thus they were not analyzed further. The eight problems where base-rate information conflicted with individuating information were analyzed. The problems were structured so that the participant had to make an inductive inference in a simulation of a real-life decision. The information relevant to the decision was conflicting and of two different types. One type of evidence was statistical—either probabilistic or aggregate base-rate information that favored one of the bipolar decisions (the analytic response). The other evidence was a concrete case or personal experience that pointed in the opposite direction (the heuristic response). An example follows:

> Erica wants to go to a baseball game to try to catch a fly ball. She calls the main office and learns that almost all fly balls have been caught in section 43. Just before she chooses her seats, she learns that her friend Jimmy caught 2 fly balls last week sitting in section 10. Which section is most likely to give Erica the best chance to catch a fly ball?

(a) Definitely section 43.
(b) Probably section 43.
(c) Probably section 10.
(d) Definitely section 10.

Selection of options a or b (scored 4 and 3, respectively) indicates the use of the aggregate base-rate information. Selection of options c or d (scored 2 and 1, respectively) indicates that the participant is using the individuating information of lower diagnosticity. For each problem, the scale ranged from 1 to 4, with higher scores indicating the analytic response (use of the aggregate base-rate information). Twenty-six of 28 possible correlations between items were positive and the mean correlation between items was .20. Total scores for each participant ranged between 8 and 32 on this task. The total score displayed a .91 correlation with a 0/1 scoring system, and the latter displayed virtually identical associations with other variables as the total score. Because the latter uses all of the information in the scale, it was employed in analyses that follow.

Deductive reasoning task

The deductive reasoning task utilized syllogistic reasoning problems taken from the work of Markovits and Nantel (1989) and adapted in a manner more suitable for use with children (see Stanovich, West, & Harrison, 1995). Students were read a script asking them to pretend that an alien from another planet had landed on Earth. The script read, "The alien's thought processes are very logical, but it knows nothing about Earth. The alien will be told a number of things about Earth but some of the information might be false." The students were then instructed to give their opinion about what the logical alien would conclude based on what it had been told. Two premises and a conclusion were read. Then, the students circled "Yes" or "No" to indicate whether they agreed or disagreed that the alien would draw the stated conclusion.

For four of the problems, believability and validity were in the same direction. In other words, a believable conclusion was valid or an unbelievable conclusion was invalid. These were termed "consistent" problems. Students from all groups performed close to ceiling on these problems and they were not analyzed further. For the remaining four problems, the valid solution required conclusions that conflicted with the believability of the content. In other words, a believable conclusion was invalid or an unbelievable conclusion was valid. These were termed "inconsistent" problems. An example of a problem with a valid conclusion consisting of unbelievable content follows:

*The logical alien is told...*All mammals walk.
*The alien is also told...*Whales are mammals.
*The logical alien would conclude...*Whales walk.

Responses on each item were coded 1 for correct or 0 for incorrect. Higher scores indicated the analytic response (the response in accord with logical validity). Scores ranged from 0 to 4. The total raw score for each student was used in the analyses.

Two practice problems were administered. One of the practice problems was logically valid (like this one) and the other was logically invalid. Each participant was provided feedback from a script that articulated the reasoning behind the correct response whether or not they had arrived at the correct conclusion. Upon completion of the practice problems, participants were read (while they followed the written text) the eight syllogistic reasoning problems.

Probabilistic reasoning task

The probabilistic reasoning task was a marble game that was modeled on a task introduced by Kirkpatrick and Epstein (1992) (see also Denes-Raj & Epstein, 1994). The investigator advised participants that the task involved trying to understand how different people play a game of chance, and that the object of the game was to try to choose a white marble from either a small or large container. Each container had a different number of white and blue marbles. Participants were told that they would be awarded one point for each white marble selected, but no points for each blue marble. No reward was associated with the number of points obtained. This instruction was simply used to further engage the participants in the marble game task. Five trials were run.

The small container always contained 10 marbles (1 white and 9 blue), and thus presented a 10% chance of selecting a white marble. The large container always contained 100 marbles. Trials one, three, and five utilized 9 white marbles and 91 blue marbles, and thus presented a 9% chance of selecting a white marble. Trials two and four utilized 8 white marbles and 92 blue marbles, and thus presented an 8% chance of selecting a white marble.

For each trial, the investigator placed both containers on a table in front of the participant, along with cue cards for each container. The cue cards stated the number of white marbles and the total number of marbles in the container, as well as the percentage of white marbles in the container. Thus, the cue card in front of the small container always read:

1 in 10

or

10% chance

The cue card in front of the large container on trials one, three, and five read:

9 in 100

or

9% chance

Correspondingly, the cue card in front of the large container on trials two and four read "8 in 100 or 8% chance".

During this process, the investigator pointed to each container and read the information from the relevant cue card. Once the investigator had ascertained that the participant understood the game, the participant was asked to choose a container. The investigator removed the non-selected container from the table, and placed a shield in front of the selected container to prevent the participant from seeing the marbles while he or she made a choice. Then, the investigator scrambled the marbles in the selected container, and asked the participant to choose a marble. The investigator recorded the size of container and the color of the marble selected on a score sheet. Once this process was complete, the investigator returned the non-selected container to the table. The table placement of the small and large container was swapped after trial two.

Although the color of the marble chosen and the points earned were recorded, these data were not used in the statistical analyses. Instead, the key variable was the container size chosen on each trial. The small container (with 1 in 10 odds of picking a white marble) was deemed the analytic choice and assigned the score of one. The large container (with 9 in 100 or 8 in 100 odds of picking a white marble) was deemed the heuristic choice, and assigned the score of zero. Possible aggregate scores on this task ranged from 0 to 5—with higher scores indicating more analytic responses. Across the entire sample, 57% of the responses were the analytic choice, a proportion greater than chance ($p < .01$).

Analytic processing composite score

An analytic processing composite score was formed by amalgamating the scores from the three reasoning tasks. Specifically, the raw scores on the inductive, deductive, and probabilistic reasoning tasks were converted to z-scores, and these z-scores were summed to form the analytic processing composite score.

Thinking dispositions questionnaire: Measures of epistemic regulation

The thinking dispositions questionnaire was a 53-item questionnaire composed of a number of subscales that were intermixed. The participants responded to each item on a four-point scale that ranged from strongly agree (1) to strongly disagree (4).

Flexible thinking scale. Items on the flexible thinking scale were adapted for children from the adult scale developed by Stanovich and West (1997). Items tap flexible thinking as a multifaceted construct encompassing the cultivation of reflectiveness rather than impulsivity (“If I think longer about a problem I will be more likely to solve it”), willingness to consider evidence contradictory to beliefs (e.g., “People should always consider evidence that goes against their beliefs.”), willingness to consider alternative opinions and explanations (e.g., “A person should always consider new possibilities.”), and a tolerance for ambiguity combined with a willingness to postpone closure (e.g., “Changing your mind is a sign of weakness.”— which is reverse scored). There were 10 items on the scale.

Belief identification. The belief identification scale was developed by Sá et al. (1999) based on a theoretical paper by Cederblom (1989) in which he argues for a potential thinking disposition centered around the extent to which people identify their beliefs with their concept of self. That scale was adapted for children in the present investigation and consisted of six items (e.g., “I never change what I believe in—even when someone shows me that my beliefs are wrong”).

Absolutism. This scale was adapted for children from the Scale of Intellectual Development (SID) developed by Erwin (1981, 1983). The SID represents an attempt to develop a multiple-choice scale to measure the early stages of Perry’s (1970) model of intellectual development in young adulthood which are characterized by cognitive rigidity, by a belief that issues can be couched in either/or terms, that there is one right answer to every complex problem, and by reliance on authority for belief justification. The present scale consisted of five items (e.g., “A good person usually does what they are told to do”).

Dogmatism. The dogmatism subscale consisted of six items. It was adapted for children from the short-form field version (Troldahl & Powell, 1965) of Rokeach’s (1960) dogmatism scale as well as other sources (see Paulhus & Reid, 1991 and Robinson, Shaver, & Wrightsman, 1991). Examples included “If everybody in a group has too many different ideas, the group will break up.” and “It really makes me angry when someone can’t say they are wrong.”

Categorical thinking. Three items were adapted for children from the categorical thinking subscale of Epstein and Meier’s (1989) constructive thinking inventory (e.g., “There are basically two kinds of people in this world, good and bad;" "There is one right way and lots of wrong ways to do most things;" and "I think people are either with me or against me").

Superstitious thinking. This eight-item scale was adapted for children from one used with adults by Stanovich and West (1997). The items were drawn from a variety of sources (e.g., Epstein & Meier, 1989; Jones, Russell, & Nickel, 1977; Stanovich, 1989; Tobacyk & Milford, 1983). Examples are: "I have things that bring me luck;" "The number 13 is unlucky;" "It's a good idea to consult your horoscope every day;" "I do not believe in any superstitions (reverse scored)".

Need for cognition scale. This nine-item scale was adapted for children from the 18-item-adult scale described by Cacioppo, Petty, Feinstein, and Jarvis (1996). An example item is: "I like hard problems instead of easy ones." The split-half (odd-even) reliability (Spearman–Brown corrected) of the scale was .67.

Social desirability response bias. Five items reflecting social desirability response bias (Furnham, 1986; Paulhus & Reid, 1991) were taken from the Balanced Inventory of Desirable Responding (Paulhus, 1991): "I always obey rules even if I probably won't get caught"; "I like everyone I meet"; "I sometimes tell lies if I have to"; "There are times I have taken advantage of someone" and "I have said something bad about a friend behind his or her back."

Actively openminded thinking composite scale. The actively openminded thinking (AOT) composite scale was created by combining the following scales: flexible thinking, belief identification, absolutism, dogmatism, and categorical thinking. The mean correlation between these subscales was .32. The scores for the items within each subscale were summed and the summed subscale score was converted to a *z*-score. On the flexible thinking scale, high scores indicated actively openminded thinking, while high scores on the other four scales indicated lack of openness. Therefore, the *z*-score for the flexible thinking scale was reflected so that the scores of all five subscales were in the same direction. Next, the five *z*-scores were summed. This score was then multiplied by −1 so that a positive score indicated increasing openness and a negative score indicated lack of openness. The split-half reliability of the 30 items in the AOT composite scale was .79 (Spearman–Brown corrected). An alternative composite scale was constructed by computing the raw sum of the five scales (i.e., without equal weighting of the scales, as in the case of the *z*-score sum). The correlation between the raw sum of scores and the *z*-score sum was .99. Thus, only the *z*-score sum was used in the analyses that follow.

Reflectivity/impulsivity: The matching familiar figures test (MFFT)

The Matching Familiar Figures Test (MFFT) was used to measure the dimension of reflectivity and impulsivity. The MFFT version developed by

Kagan, Rosman, Day, Albert, and Phillips (1964) was employed in the present study. In this task, participants were presented with a target picture of an object, and their task was to find the correct match from an array of six pictures. Participants' latency and number of errors were measured for each choice and for each item. When participants made an incorrect selection, they were asked to select again. This was repeated until the participant found the correct match (up to a maximum of six possible responses).

The mean time to the first response for all items and the number of items on which the participant made at least one error were standardized for each participant. The standardized error metric was called $\mathrm{MFFT}_{\mathrm{Errors}}$ and the standardized metric for reaction time was called $\mathrm{MFFT}_{\mathrm{RT}}$. Then the difference between these standard scores was taken to create a variable that took into account both response time and number of errors. This variable was called $\mathrm{MFFT}_{\mathrm{RT-Errors}}$. However, analyses involving this composite variable indicated that $\mathrm{MFFT}_{\mathrm{RT-Errors}}$ failed to correlate with any variable more strongly than $\mathrm{MFFT}_{\mathrm{Errors}}$ and the correlations involving $\mathrm{MFFT}_{\mathrm{RT}}$ were negligible. Therefore the $\mathrm{MFFT}_{\mathrm{Errors}}$ variable was used in the analyses that follow.

Procedure

Participants completed the tasks during a single one-hour session. All were individually tested by one of two experimenters. The order of tasks completed was: inductive reasoning task, probabilistic reasoning task, deductive reasoning task, thinking dispositions questionnaire, WISC-III Block Design subtest, WISC-III Vocabulary subtest, and MFFT.

Results

Table 2 displays the means for each of the critical reasoning tasks in the study across the two age groups and the two programs. Recall that higher scores on each of the variables (including the analytic processing composite) indicate greater tendencies toward analytic processing. A 2 (grade: 5/6 versus 8) $\times$ 2 (program: general versus gifted) analysis of variance conducted on the inductive reasoning task scores indicated that the effects of grade, $F(1,104) = 9.58$, $p < .01$, and program, $F(1,104) = 14.51$, $p < .001$, were both statistically significant, but there was no grade by program interaction, $F(1,104) = .49$. Similar results were obtained from an ANOVA on the deductive reasoning scores—significant main effects of grade, $F(1,104) = 7.58$, $p < .01$, and program, $F(1,104) = 13.16$, $p < .001$, were found, but no significant interaction, $F(1,104) = 1.21$. On

Table 2
Mean performance of the four groups on the reasoning tasks (standard deviations in parentheses)

	Grade 5/6		Grade 8	
Program:	General ($n=31$) M (SD)	Gifted ($n=26$) M (SD)	General ($n=26$) M (SD)	Gifted ($n=25$) M (SD)
Inductive reasoning task	18.94 (3.4)	20.69 (2.3)	20.29 (2.8)	22.84 (3.1)
Deductive reasoning task	1.52 (1.0)	1.96 (0.9)	1.81 (0.9)	2.64 (0.8)
Probabilistic reasoning task	2.71 (1.2)	3.15 (1.2)	2.19 (1.0)	3.48 (1.6)
Analytic reasoning composite	−1.08 (1.87)	0.25 (1.72)	−0.75 (1.60)	1.85 (2.01)

the probabilistic reasoning task[4], only the main effect of program attained significance, $F(1,104) = 12.59$, $p < .001$; neither the main effect of grade, $F(1,104) = .15$, nor the interaction were statistically significant, $F(1,104) = 2.99$.

An ANOVA conducted on the analytic reasoning composite z-score—the last variable listed in Table 2—indicated that the effects of grade, $F(1,104) = 7.62$, $p < .01$, and program, $F(1,104) = 31.75$, $p < .001$, were both statistically significant, but there was no grade by program interaction, $F(1,104) = 3.32$.

Thus, the discrete ANOVA analyses indicated that analytic processing significantly increased with age on two of the three tasks (the exception being the probabilistic reasoning task) and it increased with cognitive ability on each of the three tasks. The collective tendency for analytic processing to increase with both age and cognitive ability was confirmed by the significant main effects when the analytic reasoning composite score was analyzed.

A more complete look (and a more continuous one) at the variables that predict analytic processing on the reasoning tasks is provided in Table 3, which displays correlations between all the variables in the study. It is

[4] It has been found (e.g., Brainerd, 1981) that sometimes children adopt irrelevant strategies on probabilistic choice tasks after the first trial (e.g., alternation, perseveration). Due to such response strategies, Brainerd (1981) found that trial 1 by itself was a better indicator of age variability than aggregate indices. To examine this possibility, we ran a parallel analysis on trial 1 only and found essentially the same trends that obtained in the ANOVA on the total score collapsed across trials. The ANOVA conducted on trial 1 responses indicated that only the main effect of program attained significance, $F(1,104) = 4.20$, $p < .05$; neither the main effect of grade, $F(1,104) = .78$, nor the interaction were statistically significant, $F(1,104) = .12$.

Table 3
Intercorrelations among the primary variables

Variable	1	2	3	4	5	6	7	8	9
Reasoning tasks									
1. Inductive									
2. Deductive	.25**								
3. Probabilistic	.39***	.10							
4. Analytic composite	.77***	.64***	.70***						
Participant characteristics									
5. Age	.30**	.25**	.00	.26**					
6. Cognitive ability	.49***	.43***	.28**	.57***	.41***				
Cognitive style measures									
7. AOT composite	.43***	.40***	.17	.47***	.22*	.48***			
8. Need for cognition	.02	−.08	.25**	.09	−.24*	.09	.16		
9. Superstitious think	−.10	−.25**	−.26**	−.29**	−.12	−.30**	−.34***	−.14	
10. $MFFT_{Errors}$	−.23*	−.06	−.11	−.19	−.05	−.24*	−.23*	−.20*	.23*

Note. AOT = composite actively open minded thinking scale; $MFFT_{Errors}$ = number of item errors on the MFFT.
* $p < .05$.
** $p < .01$.
*** $p < .001$, all two tailed.

apparent that analytic processing on the inductive reasoning task was significantly correlated with analytic processing on the deductive reasoning task, $r = .25$, and probabilistic reasoning task, $r = .39$, but performance on the deductive reasoning task and the probabilistic reasoning task was not significantly correlated.

Consistent with the ANOVA results, line five of Table 3 indicates that age was significantly correlated with performance on the inductive and deductive reasoning tasks, but not significantly correlated with performance on the probabilistic reasoning task. Cognitive ability was significantly correlated with performance on each of the three tasks and displayed a moderately strong .57 correlation with the analytic processing composite score—the latter a stronger relationship than that displayed by age, $r = .26$.

The remaining section of Table 3 presents the relations involving the cognitive styles. Both need for cognition and $\text{MFFT}_{\text{Errors}}$ correlated with only one of the three reasoning tasks (probabilistic reasoning in the former case and inductive reasoning in the latter). Both the actively open-minded thinking (AOT) composite and the superstitious thinking scale correlated with two of the three reasoning tasks as well as with the analytic reasoning composite. The correlations involving the AOT tended to be the highest of all of the cognitive styles. This thinking disposition measure displayed a correlation of .47 with the analytic reasoning composite.

Unique predictors of analytic processing

A series of regression analyses were carried out to determine whether any of the cognitive styles could account for variance in analytic processing on the reasoning tasks after the variance explained by cognitive ability had been partialed out. For each of the tasks, there was at least one thinking disposition that explained unique variance over and above that explained by cognitive ability. Table 4 displays the regression analyses in which a thinking disposition was a unique predictor. For the inductive and deductive reasoning tasks, only one of the four cognitive styles explained unique variance when in a regression equation with cognitive ability. In both cases, the variable was the AOT composite. The two analyses involving that variable are displayed as the first two analyses in Table 4.

The results of these regression analyses were different for the probabilistic reasoning task. There, two of the four cognitive style measures were significant predictors of analytic processing when entered into a regression equation along with cognitive ability—and neither was the AOT composite score. The final two regression analyses reported in Table 4 reflect the two significant outcomes. Both the need for cognition score and superstitious thinking score predicted probabilistic reasoning after the variance explained by cognitive ability had been partialed. In fact, as indicated by the beta weights and unique variance explained values, the specific associations with

Table 4
Simultaneous regression analyses on the inductive, deductive, and probabilistic reasoning task performance

	β Weight	t Value	Unique variance explained	Partial r
Criterion variable = inductive reasoning				
Cognitive ability	.376	4.02***	.109	.365
AOT composite	.248	2.65**	.048	.250
Overall regression:				
$F = 21.61$***				
Multiple R = .540				
Multiple R-squared = .292				
Criterion variable = deductive reasoning				
Cognitive ability	.313	3.22**	.080	.300
AOT composite	.251	2.58*	.050	.244
Overall regression:				
$F = 16.18$***				
Multiple R = .485				
Multiple R-squared = .236				
Criterion variable = probabilistic reasoning				
Cognitive ability	.255	2.79**	.064	.262
Need for cognition	.227	2.48**	.051	.235
Overall regression:				
$F = 7.65$***				
Multiple R = .357				
Multiple R-squared = .130				
Criterion variable = probabilistic reasoning				
Cognitive ability	.216	2.24*	.042	.214
Superstitious thinking	−.199	2.07*	.036	−.198
Overall regression:				
$F = 6.64$**				
Multiple R = .335				
Multiple R-squared = .112				

Note. AOT = actively open-minded thinking scale.
* $p < .05$.
** $p < .01$.
*** $p < .001$.

each of these two cognitive style measures were almost as strong as that of cognitive ability on this task.

Table 5 displays the results of regression analyses conducted on the analytic reasoning composite variable. Each of the cognitive style variables was entered into the regression equation along with cognitive ability. Only one of the four cognitive style measures—the actively open-minded thinking composite—was a significant unique predictor once cognitive ability had

Table 5
Simultaneous regression analyses on the analytic reasoning composite scores

	β Weight	t Value	Unique variance explained	Partial r
Criterion variable = analytic reasoning composite				
Cognitive ability	.446	5.08***	.153	.444
AOT composite	.259	2.95**	.052	.277
Overall regression:				
$F = 31.63$***				
Multiple $R = .613$				
Multiple R-squared = .376				
Criterion variable = analytic reasoning composite				
Cognitive ability	.566	7.04***	.319	.566
Need for cognition	.035	.44	.002	.043
Overall regression:				
$F = 25.34$***				
Multiple $R = .571$				
Multiple R-squared = .326				
Criterion variable = analytic reasoning composite				
Cognitive ability	.531	6.39***	.256	.529
Superstitious thinking	−.129	1.55	.015	−.150
Overall regression:				
$F = 26.98$***				
Multiple $R = .583$				
Multiple R-squared = .339				
Criterion variable = analytic reasoning composite				
Cognitive ability	.557	6.74***	.292	.550
$MFFT_{Errors}$	−.053	.64	.003	−.062
Overall regression:				
$F = 25.49$***				
Multiple $R = .572$				
Multiple R-squared = .327				

Note. AOT = composite actively open-minded thinking scale; $MFFT_{Errors}$ = number of item errors on MFFT.

* $p < .05$.
** $p < .01$.
*** $p < .001$.

been partialed. It explained 5.2% additional variance after cognitive ability had been entered into the equation.

Discussion

The results of this investigation regarding cognitive ability indicated that there were moderate to strong tendencies for analytic processing to increase with increases in cognitive ability on each of the tasks. The potency of cognitive ability as a predictor was not markedly reduced by including any other variable in the study as a covariate. Like cognitive ability, age was positively related to analytic processing tendencies, but not as strongly. Age displayed a significant .26 correlation with the analytic reasoning composite score. Both the correlational and the ANOVA analyses indicated that age was positively related to analytic processing on two of the three tasks. The exception was the probabilistic reasoning task, where the ratio-bias phenomenon was more likely to be displayed by those of lower cognitive ability regardless of age.

The finding that cognitive ability and age did not display identical patterns in the study (although the directionality was the same) is perhaps not surprising because the two variables were only modestly correlated (.41) due to the oversampling of the gifted children in the study. Although the trends from the two variables converged, cognitive ability was more strongly associated with analytic processing. Predictions from dual-process theories should be more strongly confirmed by associations with cognitive ability rather than age (when the two are only modestly correlated, as in the present study) because measures of computational capacity directly reflect the likelihood of the analytic system overriding the response primed by the heuristic system in cases where the two systems are in conflict. Tasks in the heuristics and biases literature—like all three reasoning tasks in this study—are deliberately designed to put the two systems in conflict. Age is a more indirect indicator of computational capacity, and thus the cognitive ability measure should be a more potent predictor than age because it is directly tracking the crucial variable. This is precisely what a regression analysis on the analytic reasoning composite demonstrated. After age was entered, cognitive ability predicted a significant additional 25.5% of the variance. In contrast, after cognitive ability was entered into the equation, age explained only 0.1% unique variance—obviously nonsignificant.

It should be noted that the potency of cognitive ability as a predictor of analytic versus heuristic reasoning is in no way due to content overlap among the relevant measures (see Stanovich & West, 2000, for a more extended discussion of this point). First, the normative force of the instructions in the two types of tasks are vastly different. Specifically, the inductive reasoning task and probabilistic reasoning tasks are presented without implying a strict right or wrong answer and neither is an achievement test-like item. Only the deductive reasoning task bore any resemblance to items on standard cognitive ability tests, and even here the latter never contain a belief bias component. Finally, even in this task, the participant is again not focused on right or wrong but on expressing an opinion about what an alien would think. All three tasks are focused more on analytic versus heuristic *tendencies* than with limited capacity cognitive operations (such as the Block Design measure of cognitive ability) or acquired knowledge (as in the Vocabulary measure of cognitive ability).

Our study suggests one reason why the prediction of dual-process theories and other cognitive-developmental theories (e.g., Case, 1985, 1991; Inhelder & Piaget, 1958; Piaget, 1926, 1972)—that children's reasoning becomes more analytical, complex, and abstract with age—had been more consistently confirmed in the individual differences literature than in the developmental literature. The loose connection between age and cognitive ability among children in age groups not widely separated may have contributed to this pattern. Additionally, the results from the inductive reasoning task support our conjecture in the introduction about the reason for the reverse developmental trend in the Jacobs and Potenza (1991) study. The trend might have been due to the confounding effects of their "social" condition relying on knowledge of stereotypes that were less well known to the younger children (however, see Klaczynski & Narasimham, 1998; Markovits & Dumas, 1999). Our results with this task converged completely—both ANOVAs and correlational analyses indicated that the analytic response (base-rate usage) increased with age and cognitive ability.

The dual-process views that are supported by this study share many properties with recent theories of development that have emphasized the importance of inhibitory control (e.g., Case, 1992; Dempster, 1992; Dempster & Corkill, 1999; Harnishfeger & Bjorklund, 1994; Zelazo & Frye, 1998). That is, the override function of the analytic system in dual-process theories strongly resembles the role of inhibitory control in many theories that emphasize the development of executive functions. However, the ambiguous age trend in the probabilistic reasoning task might be better addressed with a model resembling fuzzy-trace theory (Brainerd & Reyna, 2001), which emphasizes more that intuitive gist-based reasoning processes increase along with the precision-based analytic processing.

It is important to understand that dual-process theories do not posit that optimal responses are never produced by the heuristic system. To the contrary, as several investigators (e.g., Klaczynski, 2001a,b; Moshman, 2000; Stanovich, 1999; Stanovich & West, 2000) have stressed, many heuristic processes are optimally designed and, secondly, normatively appropriate response tendencies can become automatized (and hence part of the heuristic system architecture) as the result of intentional practice[5] (practice often initiated due to the metacognitive abilities instantiated in the analytic system). The tasks chosen for this investigation were deliberately designed

[5] This processing sequence—analytic responses becoming instantiated in the heuristic system with practice—explains the well-known developmental trend for controlled processes to become automatized with practice. Thus, with development, more heuristic and analytic response tendencies should coincide. The developmental trend toward more analytic override tendencies with age (or, more precisely, with increases in the computational capacity of the analytic system) concerns, in contrast, instances where the outputs of the heuristic and analytic systems conflict.

(as are many in the heuristics and biases literature), for theoretical reasons, to pit heuristic and analytic processing against each other. In the majority of processing occasions in the actual environment, the outputs from these two systems will reinforce rather than oppose each other (see Stanovich, 1999, for an extensive discussion of the theoretical implications of mismatched heuristic and analytic outputs).

Finally, some cognitive style measures in our study explained unique variance in analytic reasoning tendencies, even after cognitive ability had been controlled. Our results add to a growing body of research (Dole & Sinatra, 1998; Kardash & Scholes, 1996; Klaczynski et al., 1997; Kuhn, 2001; Sá et al., 1999; Schommer, 1990, 1994; Smith & Levin, 1996; Stanovich, 1999; Stanovich & West, 1997; Toplak & Stanovich, 2002) demonstrating that intentional-level psychological constructs (e.g., cognitive styles, habits of mind) can predict analytic reasoning tendencies not entirely captured by algorithmic-level constructs such as general intelligence. Our results suggest that there are systematic differences in intentional-level psychology that are not explainable by variation in algorithmic-level capacity.

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