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Intuition and analytic processes in probabilistic reasoning: The role of time pressure

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ABSTRACT

Dual-process theories distinguish between human reasoning that relies on fast, intuitive processing and reasoning via cognitively demanding, slower analytic processing. Fuzzy-trace theory, in contrast, holds that intuitive processes are at the apex of cognitive development and emphasizes successes of intuitive reasoning. We address the role of intuition by manipulating time pressure in a probabilistic reasoning task. This task can be correctly solved by slow algorithmic processes, but requiring a quick response should encourage the use of fast intuitive processes. Adolescents and undergraduates completed three problems in which they compared a small-numbered ratio (which was always 9-in-10) to a large-numbered ratio that varied: a) 85-in-95 (smaller than 9-in-10); b) 90-in-100 (equal to 9-in-10); and c) 95-in-105 (larger than 9-in-10). Surprisingly, time pressure did not affect performance. Intelligence, cognitive reflection, and numeracy were correlated with performance, but only under time pressure. Advanced reasoning processes can be fast, intuitive, and contribute to cognitive abilities, in accordance with fuzzy-trace theory.

1. Introduction

Dual-process theories have been proposed to explain human reasoning and judgment. The central feature of these theories is the attribution of responses to two types of thinking described either as heuristic versus analytic (Evans, 1989), associative versus rule-based (Sloman, 1996), experiential versus analytic (Epstein, 1991), System 1 versus System 2 (Stanovich, 1999), gist versus verbatim (Reyna & Brainerd, 1995) or Type 1 versus Type 2 (Evans, 2008). Although there are many points of disagreement, theorists generally agree that there are heuristic processes (Type 1) that are fast, automatic, unconscious, and require low effort (Kahneman, 2003; Kahneman & Klein, 2009). Many adult judgment biases are considered a consequence of these fast heuristic responses, also called default responses, because they are the first responses that come to mind. Type 1 processes are a central feature of intuitive thinking, requiring little cognitive effort or control (Betsch & Glöckner, 2010; Glöckner & Betsch, 2012). In contrast, analytic (Type 2) processes are considered slow, conscious, deliberate, and effortful, and they place demands on central working memory resources. Hence, Type 2 processes are thought to be related to individual differences in cognitive capacity and Type 1 processes are thought to be independent of cognitive ability (Evans & Stanovich, 2013, Table 1), a position challenged by the research presented in this paper.

Thinking is described in many of these theories as an interplay between qualitative-heuristic and quantitative-analytic processing. According to fuzzy-trace theory, intuitive reasoning arises from qualitative-heuristic processes operating on the gist or essential meaning of a problem. Quantitative-analytic processes are more detail-oriented and operate on verbatim representations of a problem. With increasing age, education, and practice in a problem domain, people become increasingly skilled at extracting and processing gist and increasingly reliant on intuition. Thus, fuzzy-trace theory places intuition at the apex of development (Reyna, 2004, 2012, 2013), unlike other dual-process theories. Experts are able to grasp the gist of a situation quickly within their domain of expertise, whereas novices employ cognitively demanding analytic processes that manipulate verbatim elements of the problem description. Whereas other dual-process theories attribute much intelligent behavior to skilled analytic reasoning, fuzzy-trace theory emphasizes the role of intuitive reasoning. Both kinds of reasoning are assumed to occur simultaneously, and task demands constrain which kind is the basis for behavior (Reyna & Brainerd, 1995, 2011).

The relative contributions of heuristic and analytic processing to intelligent behavior and how conflicts between these processes are resolved constitute important questions. One promising approach to exploring these issues is the study of the relationship between performance in tasks involving dual processes and individual differences in cognitive abilities, attitudes, and preferences. Stanovich and West

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Table 1
Proportion of preferences (correct responses in bold) for three populations when self paced.

Sample population	Problem	Preference		
		Container A (9-in-10)	Container B (more numerous)	No difference
High School ($N = 56$)	9:10 versus 85:95	**.66**	.14	.20
	9:10 versus 90:100	.14	.11	**.75**
	9:10 versus 95:105	.38	**.30**	.32
Padova ($N = 39$)	9:10 versus 85:95	**.69**	.18	.13
	9:10 versus 90:100	.18	.05	**.77**
	9:10 versus 95:105	.36	**.28**	.36
Cornell ($N = 30$)	9:10 versus 85:95	**.80**	.10	.10
	9:10 versus 90:100	.10	.13	**.77**
	9:10 versus 95:105	.13	**.80**	.07

(1998; see also Stanovich, West, & Toplak, 2012) presented a comprehensive analysis of individual differences on tasks from the reasoning literature and from the heuristics and biases literature. They found that performance on tasks involving deductive reasoning, inductive reasoning, methodological thinking, and heuristic reasoning was significantly correlated. A substantial amount of variance in performance on these tasks was explained by individual differences in cognitive abilities and thinking dispositions. They interpreted the significant correlations with cognitive abilities as evidence that performance in these rational thinking tasks is influenced–to some extent–by algorithmic limitations, implicating Type 2 processing. More recently, Toplak, West, and Stanovich (2013) developed a seven-item version of the Cognitive Reflection Test (CRT; Frederick, 2005; Toplak, West, & Stanovich, 2011) and found that it was a strong predictor of performance on rational thinking tasks in which automatic processes applied by default are expected to yield a non-normative result. CRT was interpreted as measuring participants' readiness to engage Type 2 processes that would override automatic Type 1 processes. Klaczynski (2014) explored the relationships between thinking dispositions, general ability, numeracy, and performance on a similar set of problems. He found that numeracy affected performance but only at relatively high levels of thinking dispositions and general ability.

Peters et al. (2006) studied the contribution of numeracy to performance on judgment and decision tasks. Peters et al. concluded that high-numerate participants are more likely to retrieve and use appropriate numerical principles, which is relevant to verbatim or algorithmic processes. They also found that higher numerate participants draw more affective meaning from numbers, which is consistent with intuitive gist-based reasoning. Liberali, Reyna, Furlan, Stein, and Pardo (2012) employed both objective and subjective numeracy scales and showed that different aspects of numeracy predict different biases and fallacies on reasoning tasks. Based on two studies of participants from three countries, dimensions of numeracy included computational skills such as algorithmic processing but also included understanding relative magnitudes, which corresponds to the gist-based reasoning of fuzzy-trace theory. Whether individual differences in performance on numeric tasks are due to heuristic or algorithmic processes depend on properties of the task and the skills of respondents.

Imposing time pressure during the performance of a task offers a way to substantially constrain the roles of the two types of processes and assess their relationships to abilities. When a task is self-paced, both types of processes can contribute to performance, but with all other factors equal, time pressure diminishes the opportunity for contributions from slow algorithmic processes. For example, Evans and Curtis-Holmes (2005) found that time pressure caused an increase in biased responses to a syllogistic reasoning task attributed to fast heuristic processes and a decrease in correct responses attributed to slow analytic processes. When a task is performed under time pressure that effectively diminishes the contribution of slow processes, a significant correlation between performance and relevant abilities or dispositions is evidence of the contribution of fast processes (gist-based intuition or heuristics) to those abilities. A significant correlation without time pressure is evidence of the contribution of slow processes (verbatim or analytic) under task conditions that elicit those processes (Reyna & Brainerd, 2008).

We investigated the role of fast and slow processes in a probabilistic reasoning task consisting of three problems. In each problem, participants were asked to choose between two containers of marbles for a chance to draw a winning marble. The ratios of winning to losing marbles were manipulated, requiring that participants judge which ratio was larger or whether they were the same size. In one problem the ratios were 9/10 and 90/100, which are ratios that have frequently been used to study ratio biases and the roles of heuristic and analytic processes (or intuitive and verbatim reasoning) in solving these problems (Kirkpatrick & Epstein, 1992). These two ratios have, of course, equal value, but many people do not view them as equivalent. In ratio bias problems such as this one, participants tend to select the ratio with the larger numerator, neglecting the denominator (Reyna & Brainerd, 1994, 2008).

The other two of our three problems were much more difficult to solve, but one of the ratios was always 9/10. The other ratio was 85/95 in one problem and 95/105 in the other problem. These ratios were chosen to create comparison problems that would be difficult to solve using algorithmic or verbatim processes.

There have been investigations of the relationship between performance on similar probabilistic reasoning problems and cognitive abilities and thinking dispositions. Toplak et al. (2013) studied the relationship between CRT and performance on a denominator-neglect task similar to this probabilistic reasoning task. Participants chose to draw a winning marble from one of two trays, one with few and one with many marbles. The ratios of winning to losing marbles in the two trays required difficult comparisons (e.g., 1:4 versus 19:81, 1:19 versus 4:96, and 2:3 versus 19:31). They found that CRT scores were significantly correlated with performance, which they interpreted as evidence that participants with a disposition to engage analytic processes achieve better performance. Liberali et al. (2012) studied the relationship between numeracy and performance on one problem of the probabilistic reasoning task comparing 9/10 and 90/100, the classic ratio bias problem. They found that performance on this problem was related to the aspect of numeracy that involves conceptualizing the gist of numbers.

Without time pressure, participants may respond based on time-consuming algorithmic analysis or by intuitive comparisons of numeric gist. They could compare the two ratios by computing their decimal equivalent via long division or they could transform the denominators so they have common denominators and then compare the numerators. Either of these methods is easily applied to 9/10 and 90/100 and we expect high performance for this problem, but performing the mental arithmetic to determine that $85/95 = 0.895$ or transforming the ratios to have a common denominator of 950 is difficult and time-consuming. People who have a lot of experience and practice with numbers may, however, already know that adding a positive constant to the numerator and denominator of a fraction yields a larger number and subtracting a constant yields a smaller number. They could draw on this knowledge to respond quickly. Another alternative is that they may form a mental