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## The complexity of developmental predictions from dual process models

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### ABSTRACT

Drawing developmental predictions from dual-process theories is more complex than is commonly realized. Overly simplified predictions drawn from such models may lead to premature rejection of the dual process approach as one of many tools for understanding cognitive development. Misleading predictions can be avoided by paying attention to several cautions about the complexity of developmental extrapolations. The complexity of developmental predictions follows from the fact that overall normative responding at a given age derives from several different mental characteristics: (1) the developmental course of Type 1 processing, (2) the developmental course of Type 2 processing, (3) the acquisition of mindware usable by Type 1 processing, (4) the acquisition of mindware usable by Type 2 processing, and (5) the practicing of the mindware available to Type 2 processing to the extent that it is available to be processed in an autonomous manner. The complexity of all these interacting processes and sources of information can sometimes result in U-shaped developmental functions on some heuristics and biases tasks, making younger children look like they are responding more optimally than older children. This is particularly true when the youngest groups are ill-equipped to even understand the task and thus respond randomly. A final caution concerns terminology: The terms normative or rational should be reserved for responses and not attributed to subpersonal processes.

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## Introduction

Dual-process theories of cognition have received a notably large share of attention in the last decade (Evans, 2008, 2010; Evans & Frankish, 2009; Kahneman & Frederick, 2002, 2005; Lieberman, 2003, 2007; Reyna, 2004; Stanovich, 2004, 2011). And in parallel, they also have received a sizable share of criticism (Keren & Schul, 2009; Kruglanski & Gigerenzer, 2011; Osman, 2004). Our purpose here is not to attempt an overall assessment of the state of play in this literature. Instead, our goal is to caution that drawing developmental predictions from dual-process theories is a deceptively complex endeavor. Our contention is that developmental predictions are more complex than is commonly realized. Drawing overly simplified predictions from such models may lead to a premature rejection of the dual process approach as one of many tools for understanding cognitive development.

## A generic dual-process account

For our purposes here, we will lay out only the most generic of dual-process models. None of our arguments will depend on adjudicating the detailed differences among the many such models that have been discussed in the literature (see the reviews of Evans, 2003, 2006, 2008, 2009, 2010, for more detailed explications). The family resemblances among these models extend to the names for the two classes of processes. The terms heuristic and analytic are two of the oldest and most popular (see Evans, 1984, 1989). However, in order to attenuate the proliferation of nearly identical theories, Stanovich (1999) suggested the more generic terms System 1 and System 2. Although these terms have become popular, there is an infelicitousness to the System 1/System 2 terminology. Such terminology seems to connote that the two processes in dual process theory map explicitly to two distinct brain systems. This is a stronger assumption than most theorists wish to make. Additionally, both Evans (2008, 2009) and Stanovich (2004, 2011) have discussed how terms such as System 1 or heuristic system are really misnomers because they imply that what is being referred to is a singular system. In actuality, the term used should be plural because it refers to a set of systems in the brain that operate autonomously in response to their own triggering stimuli, and are not under higher-level cognitive control.

Evans (2008, 2009; see also Samuels, 2009) has suggested a terminology of Type 1 processing versus Type 2 processing. The Type 1/Type 2 terminology captures better than previous terminology that a dual process theory is not necessarily a dual system theory (see Evans, 2008, 2009, for an extensive discussion). For these reasons, I will rely most heavily on the Type 1/Type 2 terminology. An even earlier terminology due to Evans (1984, 1989)—heuristic versus analytic processing—will also be employed on occasions when it is felicitous because many developmental studies in the literature have used this terminology.

The defining feature of Type 1 processing is its autonomy—the execution of Type 1 processes is mandatory when their triggering stimuli are encountered, and they are not dependent on input from high-level control systems. Autonomous processes have other correlated features—their execution is rapid, they do not put a heavy load on central processing capacity, they tend to be associative—but these other correlated features are not defining. Autonomous processes would include behavioral regulation by the emotions; the encapsulated modules for solving specific adaptive problems that have been posited by evolutionary psychologists; processes of implicit learning; and the automatic firing of overlearned associations (Barrett & Kurzban, 2006; Carruthers, 2006; Coltheart, 1999; Evans, 2008, 2009; Moors & De Houwer, 2006; Samuels, 2005, 2009; Shiffrin & Schneider, 1977; Sperber, 1994).

For the discussion of developmental issues, it is important to realize that what is called Type 1, or heuristic processing, is a grab-bag—encompassing *both* innately specified processing modules/procedures and experiential associations that have been learned to automaticity. The point stressed by both Evans (2008, 2009) and Stanovich (2004, 2011) is that Type 1 processing is not a uniform type arising from a singular system. The many kinds of Type 1 processing have in common the property of autonomy, but otherwise, their neurophysiology and etiology might be considerably different. For example, Type 1 processing is not limited to modular subprocesses that meet all of the classic Fodor (1983)

criteria (information encapsulation, cognitive impenetrability, subserved by specific neural architecture, etc.), or the criteria for a Darwinian module (Cosmides, 1989; Sperber, 1994). Type 1 processing encompasses processes of unconscious implicit learning and conditioning. Also, many rules, stimulus discriminations, and decision-making principles that have been practiced to automaticity (e.g., Kahneman & Klein, 2009; Shiffrin & Schneider, 1977) are processed in a Type 1 manner. This point becomes relevant in the developmental literature when generic reference is made to heuristic processing. The term heuristic processing leaves ambiguous what manner of Type 1 processing is being discussed. The use of the term “heuristic processing” in the developmental literature often leaves indeterminate whether it is the innately-specified autonomous processing of a Darwinian module that is being discussed or whether it is referring to a learned association that has been practiced so much and is so highly compiled that it can now fire autonomously.

Unlike Type 1 processing, Type 2 processing is nonautonomous and, as will be discussed below, it often depends on the critical operation of cognitive decoupling. Type 2 processing is relatively slow and computationally expensive. Many Type 1 processes can operate at once in parallel, but Type 2 processing is largely serial. Type 2 processing is often language based, but it is not necessarily so. One of the most critical functions of Type 2 processing is to override Type 1 processing. This is sometimes necessary because many autonomous processes can get the response into the right ballpark when solving a problem or making a decision, but they are often not designed for the type of fine-grained analysis called for in situations of unusual importance (financial decisions, fairness judgments, employment decisions, legal judgments, etc.).

All of the different kinds of Type 1 processing (processes of emotional regulation, Darwinian modules, associative and implicit learning processes) can produce responses that are nonoptimal in a particular context if not overridden. For example, often humans act as cognitive misers (an old theme in cognitive/social psychology, see Dawes, 1976; Simon, 1955, 1956; Taylor, 1981; Tversky & Kahneman, 1974) by engaging in attribute substitution—the substitution of an easy-to-evaluate characteristic for a harder one, even if the easier one is less accurate (Kahneman & Frederick, 2002, 2005). For example, the cognitive miser will substitute the less effortful attributes of vividness or affect for the more effortful retrieval of relevant facts (Kahneman, 2003; Li & Chapman, 2009; Slovic & Peters, 2006; Wang, 2009). But when we are evaluating important risks—such as the risk of certain activities and environments for our children—we do not want to substitute vividness for careful thought about the situation. In such situations, we want to employ Type 2 override processing to block the attribute substitution of the cognitive miser.

Kahneman and Frederick (2002) provide a number of examples of how attribute substitution can lead people into irrational response patterns. In one experiment, one group of participants was asked to estimate the number of murders that occurred in Michigan during a particular year. This is a difficult task, because people must retrieve relevant facts (the population of the state, what they have heard about the crime there, and other cues) that they can then put together to come up with an estimate. That people were not working too hard in coming up with information with which to derive an estimate (that they were cognitive misers) is suggested by the fact that another group of subjects who were asked to estimate the number of murders in Detroit in a year came up with an estimate that was twice as large as the Michigan group! Because the image of Detroit is associated with more affect-laden murder imagery than is the image of Michigan, the former as a stimulus generates a higher murder number even though on a logical or empirical basis this could not be the case. For similar reasons, forecasters assigned a higher probability to “an earthquake in California causing a flood in which more than 1000 people will drown” than to “a flood somewhere in the United States in which more than 1000 people will drown.” Of course, an image of a California earthquake is very accessible and its ease of accessibility affects the probability judgment.

In order to override Type 1 processing, Type 2 processing must display at least two related capabilities. One is the capability of interrupting Type 1 processing and suppressing its response tendencies. Type 2 processing thus involves inhibitory mechanisms of the type that have been the focus of work on executive functioning (Aron, 2008; Best, Miller, & Jones, 2009; Hasher, Lustig, & Zacks, 2007; Miyake, Friedman, Emerson, & Witzki, 2000; Zelazo, 2004). But the ability to suppress Type 1 processing gets the job only half done. Suppressing one response is not helpful unless there is a better response available to substitute for it. Where do these better responses come from? One answer is that

they come from processes of hypothetical reasoning and cognitive simulation that are a unique aspect of Type 2 processing (Evans, 2007, 2010; Evans, Over, & Handley, 2003). When we reason hypothetically, we create temporary models of the world and test out actions (or alternative causes) in that simulated world. In order to reason hypothetically we must, however, have one critical cognitive capability—we must be able to prevent our representations of the real world from becoming confused with representations of imaginary situations.

The so-called cognitive decoupling operations are the central feature of Type 2 processing that make this possible, and they have implications for how we conceptualize both intelligence and rationality (Stanovich, 2004, 2009, 2011). In a much-cited article, Leslie (1987) modeled pretense by positing a so-called secondary representation (see Perner, 1991) that was a copy of the primary representation but that was decoupled from the world so that it could be manipulated—that is, be a mechanism for simulation. The important issue for our purposes is that decoupling secondary representations from the world and then maintaining the decoupling while simulation is carried out is a Type 2 processing operation. It is computationally taxing and greatly restricts the ability to conduct any other Type 2 operation simultaneously. In fact, decoupling operations might well be a major contributor to a distinctive Type 2 property—its seriality.

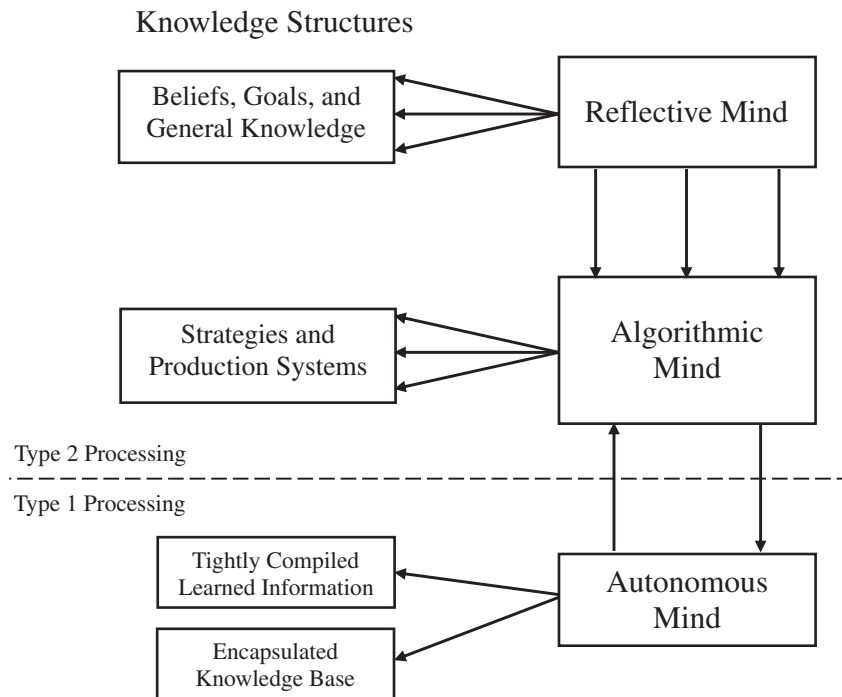
Stanovich (2009, 2011) differentiated two aspects of Type 2 processing stemming from the fact that instructions to initiate override of Type 1 processing (and to initiate simulation activities) and the cognitive machinery to carry out decoupling probably represent different mechanisms. Type 2 processing thus needs to be understood in terms of two levels of cognitive control—what were termed the algorithmic level and the reflective level of Type 2 processing. To understand the difference, we can turn to an old distinction in psychometrics—that of individual differences that derive from typical performance situations and individual differences that derive from optimal (sometimes termed maximal) performance situations (see Ackerman, 1994, 1996; Cronbach, 1949; Matthews, Zeidner, & Roberts, 2002; Sternberg, Grigorenko, & Zhang, 2008). Typical performance situations are unconstrained in that no overt instructions to maximize performance are given, and the task interpretation is determined to some extent by the participant. The issue is what a person would typically do in such a situation, given few constraints. Typical performance measures are measures of the reflective mind (Stanovich, 2009)—they assess in part goal prioritization and epistemic regulation. Measures of cognitive style and thinking dispositions assess the reflective level of cognition. Examples of some thinking dispositions that have been investigated by psychologists are: actively open-minded thinking, need for cognition, consideration of future consequences, need for closure, superstitious thinking, and dogmatism (Cacioppo, Petty, Feinstein, & Jarvis, 1996; Kruglanski & Webster, 1996; Stanovich, 1999, 2009; Sternberg, 2003; Strathman, Gleicher, Boninger, & Scott Edwards, 1994).

In contrast, optimal performance situations are those where the task interpretation is determined externally. The person performing the task is instructed to maximize performance. Thus, optimal performance measures examine questions of the efficiency of goal pursuit—they capture the processing efficiency of the algorithmic mind. All tests of intelligence or cognitive aptitude are optimal performance assessments.

### **Learned associations and automatically-accessed knowledge bases are part of dual process theory**

One thing that has complicated the derivation of developmental predictions from dual-process models is that it is easy to forget that the simulation process is not simply procedural but instead utilizes content—that is, it uses declarative knowledge and strategic rules (linguistically-coded strategies) to transform a decoupled representation. In the early dual-process literature (especially prior to 2000), the knowledge bases and strategies that are brought to bear on the secondary representations during the simulation process were given little attention.

In fact, each of the levels in the tripartite model described previously has to access knowledge to carry out its operations (see Fig. 1). The reflective mind not only accesses general knowledge bases and strategies but, importantly, accesses the person's opinions, beliefs, and reflectively acquired goal structure (considered preferences, see Gauthier, 1986). The algorithmic mind accesses primarily



**Fig. 1.** Knowledge structures in the tripartite framework.

strategies for cognitive operations and production system rules for sequencing behaviors and thoughts. Finally, the autonomous mind accesses not only evolutionarily-compiled encapsulated knowledge bases, but also retrieves information that has become tightly compiled due to overlearning and practice. It is important to note that what is displayed in Fig. 1 are the knowledge bases and strategies that are unique to each mind. Algorithmic- and reflective-level processes also receive inputs from the computations of the autonomous mind. As Evans (2006, 2008, 2009) notes, autonomous-level processes that supply information to the analytic system are sometimes termed preattentive processes.

The rules, procedures, and strategies that can be retrieved by the algorithmic and reflective minds and used to transform decoupled representations have been referred to as mindware, a term coined by Perkins in a 1995 book (Clark, 2001, uses it in a slightly different way from Perkins' original coinage). The mindware available for the construction of an alternative response to substitute during the override of Type 1 processing is in part the product of past learning experiences. Indeed, if one is going to trump an autonomous response with conflicting information or a learned rule, one must have previously learned the information or the rule. Thus, for successful autonomous system override to take place three mental characteristics (two process characteristics and one knowledge characteristic) must be present. First, sufficient cognitive capacity is needed in order that override and simulation activities can be sustained. Second, the reflective mind must be characterized by the tendency to initiate the override of suboptimal responses generated by the autonomous mind and to initiate simulation activities that will result in a better response. Finally, the mindware that allows the computation of rational responses needs to be available and accessible during simulation activities. Problems in rational thinking arise when the cognitive capacity is insufficient to sustain autonomous system override, when the necessity of override is not recognized, or when simulation processes do not have access to the mindware necessary for the synthesis of a better response. In the latter case, the necessary mindware could be either missing or supplanted by alternative maladaptive mindware (e.g., gambler's fallacy).

Notice that there is ambiguity in the phrase "override failure" used in the older dual-process literature. Sometimes, when override failures occur, sufficient algorithmic-level cognitive capacity is present, but that capacity is not called upon by the reflective mind. In such cases, the algorithmic mind is not called up to exhibit its inhibitory powers, and no override occurs. However, if the relevant

mindware is not available for substitution because it has not been learned, then we have a case that is better characterized as missing mindware (see Stanovich, 2009) rather than override failure. These distinctions among the reasons why necessary overrides might not take place are often ignored in the developmental literature.

It is important to note that an analogous distinction was present in fuzzy-trace theory from the beginning (Reyna & Brainerd, 1995). That dual-process theory likewise recognizes the difference between reasoning errors that arise from the lack of knowledge of a reasoning principle and those that arise from the failure to inhibit interference from irrelevant verbatim information (see Table 7.5 of Reyna, Lloyd, & Brainerd, 2003).

Additionally, it is important to acknowledge the existence of tightly compiled knowledge bases (see Fig. 1) in the autonomous mind. The autonomous mind contains not only the knowledge bases encapsulated in Darwinian modules (see Fig. 1). It can come to contain high-level analytic knowledge learned over extended periods of time, including many normative rules of rational thinking (Baron, 2008; Stanovich, 1999) as well important cue-validities that are picked up inductively (Cooksey, 1996; Doherty & Kurz, 1996; Kahneman & Klein, 2009). For example, in Klein's (1998) writings about firefighters, he found that the experts among them made mostly what he termed "recognition-primed" decision making. That is, an autonomous retrieval of highly diagnostic cues seemed to be the basis of their expert performance. Of course, the cues had been induced and compiled during extensive previous periods of Type 2 processing.

The presence of learned information in the autonomous mind has been stressed in cognitive psychology ever since one of the earliest dual-process models described by Shiffrin and Schneider (1977) and Schneider and Shiffrin (1977) in their studies of detection, search, and attention in cognitive psychology. Their model differentiated automatic from controlled processing.<sup>1</sup> Parallel to the generic features described previously, they conceived controlled processing as requiring active attention, being serial in nature, but being applicable in novel situations where automatic sequences have not been learned. They conceived automatic processes to be unhindered by capacity limitations, attentionless, parallel, independent of one another, and ballistic. Importantly, they posited that acquired automatic processes required considerable training to develop, and that they are difficult to modify once learned. Thus, tightly compiled learned information is a crucial component of the classic dual-process model of Shiffrin and Schneider (1977) and Schneider and Shiffrin (1977). Importantly for our discussion of developmental predictions, they stress an acquisition sequence beginning with controlled processes lacking critical mindware, to the ability of controlled processes to deal with a certain class of mindware, to—finally, via controlled practice, the mindware becoming highly compiled and able to trigger in the manner of an automatic process. They emphasize that "it should not be overlooked that the initial learning of automatic processing may require a variety of control processes and hence will be subject to various limitations that may disappear when learning has progressed to a high level" (Shiffrin & Schneider, 1977, p. 158; for a related contemporary view, see Reyna et al., in press; and Reyna et al., 2003). Thus, mindware more generally, and the presence of tightly compiled knowledge bases more specifically, is highly relevant to any examination of developmental trends in rational thinking.

### **Developmental dual-process predictions: the many ways they can be misconstrued**

Seemingly, the easiest developmental prediction one might draw from dual-process theories is that Type 2 thought should replace Type 1 thought as children age. But in fact this prediction does not follow from most dual-process theories. For example, in the context of fuzzy-trace theory, the prediction is a form of what Brainerd and Reyna (2001) term the "illusion of replacement" (p. 52)—the idea that analytic thought replaces heuristic thought. Brainerd and Reyna (2001) describe how both analytic and heuristic thought might increase with age under the assumptions of their dual-process view—fuzzy-trace theory. As discussed in the context of the Shiffrin and Schneider (1977) theory

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<sup>1</sup> The "controlled" processing language of Shiffrin and Schneider (1977) is perhaps inapt given the admonition of several dual-process theorists (Evans, 2011; Stanovich, 2004) that System 2 not be conceived as a homunculus. This issue is not germane to the thrust of our point about their early work, however.

mentioned above, controlled processing can result in the efficient compilation of knowledge and procedures so that the latter become executable as automatic processes. This efficient compilation of knowledge and procedures continues apace with aging, thus providing more automatic processing opportunities. Neither in the classic dual-process view of Shiffrin and Schneider (1977), nor in other older dual-process theories (Wason & Evans, 1975), nor in more contemporary dual-process views (see Evans (2008), for a review) can Type 2 processes be said to *replace* Type 1 processing with age.

One reason that the illusion of replacement is a tempting assumption is that early dual-process theories did not stress the multifariousness of System 1—inadvertently encouraging the erroneous view that it was comprised only of innate modules. Many years ago, our research group might have contributed to this tendency. We have since attempted to correct this oversight, but it may persist among some developmental theorists. As mentioned, in order to attenuate the proliferation of nearly identical theories, Stanovich (1999) suggested the more generic terms System 1 and System 2. In actuality, the term System 1 should be plural because it refers to a set of systems in the brain that operate autonomously in response to their own triggering stimuli, and are not under higher-level cognitive control. Stanovich (2004) suggested the acronym TASS (standing for The Autonomous Set of Systems) to describe what is in actuality a heterogeneous set. For similar reasons, Evans (2008, 2009; see also Samuels, 2009) has suggested a terminology of Type 1 processing (versus Type 2 processing) that we have adopted here.

The older terminological confusion in the dual-process literature—the failure to emphasize the multifariousness of System 1 processing—inadvertently encouraged the erroneous view that System 1 consisted of only Darwinian modules. This assumption encourages the developmental prediction that, with development, more normative rules will become available to the analytic system and that this will have two consequences: that analytic processing will replace heuristic processing via override and that responses will become more normative. The latter prediction follows from the presumption that many modern problems of rational thinking derive from situations that depart from the environment of evolutionary adaptation (Stanovich, 2004, 2009). Darwinian modules firing inappropriately in a modern environment can indeed be a source of irrational responding. Thus, the gradual acquisition of mindware that allows for more rational responses to be substituted during override (probabilistic knowledge substituting for vividness, for example) seems to invite the prediction that both analytic processing and normative responding will necessarily increase with age.

However, as described above, there are more kinds of Type 1 processing than just responses triggered by Darwinian modules. And the presence of other Type 1 processes complicates predictions about the developmental course of analytic versus heuristic processing and the developmental course of normative responding. In addition to modular subprocesses that meet all of the classic Fodor (1983) criteria, Type 1 processing encompasses processes of unconscious implicit learning and conditioning. Also, many rules, stimulus discriminations, and decision-making principles that have been practiced to automaticity (Kahneman & Klein, 2009) are processed in a Type 1 manner. This learned information can sometimes be just as much a threat to rational behavior as are evolutionary modules that fire inappropriately in a modern environment. Rules learned to automaticity can be overgeneralized—they can autonomously trigger behavior when the situation is an exception to the class of events they are meant to cover (Arkes & Ayton, 1999; Hsee & Hastie, 2006). But just as surely, normative rules of rational behavior can be learned and practiced to automaticity and thus able to trigger in the manner of a Type 1 process. Some statistics instructors, for example, become unable to empathize with their students for whom the basic probability axioms are not transparent. The instructor can no longer remember when these axioms were not natural heuristic responses.

Clearly highly compiled rules that are overgeneralized to inappropriate situations would lead to the same developmental predictions as Darwinian modules in System 1. However, normative rules of rationality that are learned to automaticity complicate predictions. They of course reinforce the trend for normative responding to increase with age, but they would simultaneously reinforce a (seemingly) contradictory trend for heuristic processing to increase with age. Of course, there is really no contradiction at all. If more normative rules can be compiled and stored in System 1 with age, then heuristically-based normative responding could well increase with age. It is only the incorrect assumption that System 1 is composed of only Darwinian modules prone to inappropriately trigger that rules out developmental increases in both normative and heuristic responding.



Heuristic responses may themselves make use of mindware that may or may not be present at various stages of development. This accounts for a developmental trend sometimes found—that responses sometimes get less normative with age before they turn more normative again, a trend describable perhaps as a type of U-shaped function. These U-shaped developmental functions have been documented in fuzzy-trace theory and have played a major role in the development of that theory (Reyna & Brainerd, 1994, 1995; Reyna & Ellis, 1994; Reyna & Farley, 2006).

The U-shaped pattern can (among other reasons) arise when the responding of the youngest group is dominated by randomness because they do not even have the mindware requisite for an informed heuristic response.<sup>2</sup> With age, children acquire the mindware that enables a non-normative heuristic response. Thus, at the youngest ages, the developmental trend may well be for normative responding to decline, because random responding is more likely to hit on the normative response than is a systematically non-normative heuristic process. Finally, at the oldest ages, the children acquire the normative mindware that can be substituted during the override of Type 1 processing, and normative responses increase again. In other words, such task situations often spawn the developmental sequence: random responding followed by smart errors (see Morsanyi & Handley, 2008)—finally followed by normative responding.

Situations like this sometimes occur when the process of attribute substitution is the heuristic strategy. According to Kahneman and Frederick (2002), people engage in attribute substitution when they substitute an easy-to-evaluate characteristic for a harder one, even if the easier one is less accurate. For example, people will substitute the less effortful attributes of vividness, stereotype, or affect for the more effortful retrieval of relevant facts (Kahneman, 2003; Li & Chapman, 2009; Slovic & Peters, 2006; Wang, 2009). Note, however, that the presence of mindware is necessary for attribute substitution to work properly. Assume a person engages in attribute substitution by replacing a comprehensive analysis of diagnostic cues with a stereotype. But to engage in this type of attribute substitution, one must have stored enough exemplar information to abstract a stereotype for the situation. A child without the relevant stereotype knowledge will not be able to engage in this type of heuristic attribute substitution and would have to respond on some other basis. Thus, a situation with a misleading stereotype will tend to differentially trip up the older child rather than the younger.

The present argument concerning attribute substitution fuses with our earlier caution about compiled normative rules residing in System 1 to reinforce the two points that: (1) One cannot necessarily expect heuristic processing to decrease uniformly with age, and, (2) One cannot even expect normative responding to increase uniformly with age. All of these complications regarding developmental predictions derive from a common confusion well-discussed by Evans (2008, 2009). He points out that it is wrong to equate Type 2 processing with normatively correct responding and Type 1 processing with normatively incorrect processing. First, *both* types of processing are most often normatively correct. It is also possible for a situation to trigger a Type 1 response that is normatively correct (because normative rules have been learned to automaticity) and for the situation to spawn a Type 2 response that is normatively incorrect (because mindware used in cognitive simulation is faulty). The only claim that most dual-process theorists make is that the converse (Type 1 normatively incorrect and Type 2 normatively correct) is statistically more likely. Evans' (2008, 2009) point illustrates why certain terms for the two processes in dual-process theory are infelicitous. For example, Epstein's (1994) terminology (experiential system and rational system) mistakenly implies that Type 2 processing always yields a response that is normatively rational (and perhaps pragmatically that the experiential system does not). Gibbard's (1990) labeling of Type 2 processing as emanating from a "normative control system" mistakenly implies the same thing (that Type 2 processing is always normative), as does

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<sup>2</sup> An example of a developmental trend from an extremely primitive default (rather than randomness) toward a more sophisticated heuristic response is presented by De Neys (2006) in a study of responses to the notorious Monty Hall problem. The developmental trend in his study was not toward the correct "switch" response (which is virtually nonexistent in his sample), but instead from the primitive "stick" to the more sophisticated heuristic of "chances are equal".

Klein's (1998) labeling of Type 2 strategies as "rational choice strategies". Rationality is an organismic-level concept and should never be used to label a subpersonal process.<sup>3</sup>

Are there situations where the developmental predictions are clearer? One might expect that more monotonic developmental predictions would be possible in situations where we could ensure that the mindware for both normative responding is available for Type 2 simulation—but not highly compiled and stored in System 1. Under such conditions, it would appear that normative responding should certainly increase monotonically with age or with cognitive ability more generally. If the normative mindware could not be triggered in the manner of a Type 1 response, it would have to be substituted during override. It would seem that the greater computational capacity of the more developmentally mature would enable more of the sustained decoupling that is needed to inhibit nonoptimal Type 1 responses and carry out the simulation of a superior response.

Even in this more clearcut situation, however, complications arise that might lower the developmental correlation with normative responding. The complications involve recognizing the importance of the distinction between the algorithmic level and reflective level of Type 2 processing. Recall that rationality requires three different classes of mental constituents. First, the mindware that allows the computation of rational responses needs to be available and accessible during simulation activities. Second, algorithmic-level cognitive capacity is needed in order that override and simulation activities can be sustained. Finally, the reflective mind must have the tendency to initiate the override of suboptimal responses generated by the autonomous mind and to initiate simulation activities that will result in a better response.

This third cognitive requirement—the tendency of the reflective mind to override the autonomous mind—is only mildly correlated with algorithmic-level cognitive capacity (Ackerman & Heggstad, 1997; Bates & Shieles, 2003; Cacioppo et al., 1996; Fleischhauer et al., 2010; Nofle & Robins, 2007). Thus, it would tend to attenuate any relationship between cognitive capacity and normative responding even if all age groups had acquired the relevant mindware. In short, the mere presence of the cognitive ability to use the normative mindware does not guarantee that it will be used. The *presence* of an ability does not insure its *use*. The presence/use distinction can be the cause of confusing developmental trends. An example from the psychology of reading literature will provide an illustration. Older and more mature readers have better word prediction abilities when that is the set task. That is, when given some written textual context and told to guess the upcoming word, older readers guess more accurately than younger children (Stanovich, 2000). However, in measures of the online word recognition process, the younger readers have been found to rely more on context than older and more skilled readers (Stanovich, 2000). That is, there is a developmental mismatch between presence of an ability and its use. Despite possessing superior prediction abilities, older skilled readers rely less on such abilities during ongoing word recognition.

In the forgoing, we have laid out some potential complications in forming developmental predictions from dual-process theories. In the next section, we will point to several examples of these complications and confusions in the developmental literature.

### Examples of these conceptual confusions in the developmental literature

We will now illustrate some of these difficulties in drawing developmental predictions, as well as related conceptual confusions in developmental studies. In order to be ecumenical and fair, we will begin by discussing some confusions in a developmental study of our own, that by Kokis, Macpherson,

<sup>3</sup> We follow most cognitive scientists in deeming rationality a personal entity and not a subpersonal one (Bermudez, 2001; Davies, 2000; Frankish, 2009). A memory system in the human brain is not rational or irrational—it is merely efficient or inefficient (or of high or low capacity). Likewise our face recognition systems are not rational or irrational—they are merely efficient or inefficient. Subprocesses of the brain do not display rational or irrational properties per se, although they may contribute in one way or another to personal decisions or beliefs that could be characterized as such. Rationality concerns the actions of an entity in its environment that serve its goals. One of course could extrapolate the notion of environment to include the interior of the brain itself and then talk of a submodule that chose strategies rationally or not. This move creates two problems. First, what are the goals of this subpersonal entity—what are its interests that its rationality is trying to serve? This is unclear in the case of a subpersonal entity. Second, such a move regresses all the way down. We would need to talk of a neuron firing being either rational or irrational ("turtles all the way down!").

Toplak, West, and Stanovich (2002). For example, there, we said that “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” (p. 28). This statement is guilty of mixing apples and oranges a bit—or, more precisely, of mixing the algorithmic and reflective levels together in a confusing way. The phrasing “tendency for analytic processing to override heuristic processing” implies that we are talking about the reflective-level—that is, the disposition to signal the need to decouple. The next part of the sentence—the part about differences in computational capacity—is clearly referring to the ability of the algorithmic-level to sustain decoupling once a decoupling “call” (to use the computer programming jargon) has been made.

The thinking dispositions related to the *tendency* to initiate override and the capacity to sustain the override itself are two different mechanisms that, in our model, reside at two different levels of Type 2 processing. Our statement implies that the developmental course of these two psychological processes will be the same, which is not necessarily true. Although work on executive processing, attention, and working memory suggests a moderately strong relation with development (or intelligence within a developmental range) and the ability to sustain cognitive decoupling, data on the developmental course of the thinking dispositions related to override initiation are extremely sparse.

Later in the paper, Kokis et al. state that “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” (p. 29). Here we are guilty of just the oversimplification that was discussed in the previous section. Even in situations where normative responding increases with age, it does *not* follow that the use of heuristic processing should decrease with age. Perhaps the increased normative responding is due to rational rule that has been practiced to automaticity. If the speed with which the rule is triggered as well as the breadth of stimuli that trigger it are increasing with age, then both normative responding and heuristic processing could increase with age.<sup>4</sup>

Kokis et al. (2002), at the end of their paper, note that “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” (p. 45). Again, this is not precisely correct. Measures of computational capacity do not *directly* reflect the likelihood of the analytic system override. Computational capacity is only one of *two* things that *together* predict the overall likelihood of override: the probability of detecting the need for override in the first place (indexed by various thinking dispositions) and then the probability of sustaining the decoupling processes that simultaneously inhibit the Type 1 response and enable the simulation process where a superior response is chosen. The probability of detecting the need for override in the first place is indexed by various thinking dispositions that have been studied (Stanovich, 2011). The ability to sustain decoupling representations is indexed by fluid intelligence. Our confusing statement fused the two processes of decoupling and the call to decouple itself, as well as the individual differences measures that index them.

Our failure to sufficiently acknowledge the complications in drawing predictions from dual-process theories has unfortunately been copied and cloned by other investigators. In their interesting developmental study, Morsanyi and Handley (2008) use verbatim some of our developmental statements as exemplars of one class of dual-process theory and then try to juxtapose them against another in a “clash of theories” manuscript of the type that our journal editors love so much. In doing so, they repeat some of the predictions that our group attributed to classic dual-process models of the type that Evans (1984, 1989, 2003) had championed for many years.

For example, Morsanyi and Handley (2008) attribute to the classic accounts the individual differences prediction that “the efficiency and prevalence of analytic processing increases with development and is associated with increases in cognitive capacity within a given age group” (p. 20). Under the reasonable assumption that by analytic processing they mean Type 2 processing, this quote gets one out of two correct. This prediction is right about efficiency but not necessarily correct about

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<sup>4</sup> Note that this confusion would not occur at all if the word heuristic was used consistently in the developmental literature to refer to a (sometimes non-normative) cognitive short cut. We would then need another name for a normative rule that triggers automatically. Instead, however, “heuristic” tends to be used in the developmental literature as an umbrella term for all Type 1 processing.

prevalence. Here we have an instance of the ability versus use distinction discussed in the reading example in the previous section. *Contingent* on an override being *attempted*, then yes, with development and enhanced cognitive ability, the more developmentally advanced individual should be more likely to successfully complete an override attempt—that is, to sufficiently sustain the cognitive decoupling that is necessary. However, that does not mean that the *prevalence* of Type 2 processing should be greater in the more developmentally advanced individual. Again, for all the reasons discussed previously, the more developmentally advanced individual might not be more prone to engage in Type 2 processing to complete a particular task. The more developmentally advanced individual will be more likely to have practiced normative rules to automaticity so that they can execute as Type 1 processing. Such learning will act to *decrease* the prevalence of Type 2 processing.

Morsanyi and Handley (2008) are on even shakier ground when they claim that it follows from classic dual-process models that “analytic responding replaces heuristic responses given enough cognitive capacity” (p. 20). The phrasing of this statement encourages the view that older dual-process views suffer from the “illusion of replacement” (p. 52, Brainerd & Reyna, 2001)—the idea that analytic thought replaces heuristic thought. Even the oldest dual-process views did not posit that Type 1 processing was “turned off” when more Type 2 processing takes place. To the contrary, going back to the beginning of the heuristics and biases approach (see the summary by Kahneman & Frederick, 2002) it was assumed that even with the onset of substantial Type 2 processing, all Type 1 processes continued to operate in a somewhat ballistic, if not modular, fashion.

Additionally, and for the same reasons outlined in this section and the previous one, it does not follow, as Morsanyi and Handley (2008) argue, that “one dual-process account (e.g., Kokis et al., 2002) presupposes a negative relationship between cognitive capacity and heuristic responding” (p. 22). A similar error is made by Osman and Stavy (2006), who state that “U-shaped developmental curves are not predicted by some dual-system theories of reasoning (Evans & Over, 1996, 2004; Stanovich & West, 2000)” (p. 950) because “These indicate nonmonotonic increases in performance in a variety of cognitive and motor skills that are inconsistent with explanations of monotonic increases in the development of basic capacities—for example, working memory, metacognition, and analytical skills” (p. 950). Again, for the reasons outlined previously, monotonic increases in basic capacities do not imply monotonic decreases in heuristic processes or monotonic increases in normative responding.

It should be noted that we acknowledge that the standard version of dual-process theory used by Kokis et al. (2002) was not designed to *predict* U-shaped developmental functions. Our point is just that, in some task situations, the theory is not *inconsistent* with such functions. Fuzzy-trace theory, in contrast, can provide a positive explanatory account of some of the observed U-shaped functions (Reyna & Brainerd, 1994, 1995; Reyna & Ellis, 1994; Reyna & Farley, 2006).

### **The stimulus equivalence problem exacerbates the difficulty of drawing developmental predictions from dual-process models**

All developmental comparisons involve the difficult question of stimulus equivalency. Say an investigator wishes to investigate the developmental course of process A. The problem is that any task used to test process A will necessarily embed process A along with other processes (B, C, D, etc.) necessary to carry the task. If the younger children have differential difficulty with any of these extraneous processes it might impair their performance on the task, leading to a mistaken inference about process A if we are operating under the assumption that extraneous processes are equated.

Developmental studies in the heuristics and biases tradition are subject to a particularly interesting twist on this basic problem. Tasks of the Kahneman and Tversky (1972, 1973; Tversky & Kahneman, 1974) type are often deliberately designed to pit an enticing Type 1 response against a more deliberate and rational Type 2 solution (see Kahneman & Frederick, 2002). However, the Type 1 response sometimes depends on experiential and learning factors (stereotypes, stored frequencies, prototypes, etc.)—in short, on the presence of learned mindware. This was no problem in the classic studies, which uniformly employed mature adults. However, developmental studies, depending upon the age group involved, run the risk of testing subjects who have not had the experiential learning that is necessary

to trigger the Type 1 response. Such a situation would set up the conditions for randomly responding younger children to look more normative than slightly older children who had learned the mindware necessary to trigger the misleading Type 1 heuristic, but not the mindware necessary for the fully normative response. This is just the situation that creates the U-shaped developmental functions discussed above.

All of these problems of task equivalence in developmental studies are particularly acute when testing dual-process models where we are concerned with the complex interaction between the developmental course of many things acting simultaneously: Type 1 processing, Type 2 processing, and the mindware used by each. These complexities are certainly operating in many of the classic studies in the developmental literature. For example, in the base-rate studies by Davidson (1995) and Jacobs and Potenza (1991)—much-cited because they showed (in one condition) an increase in non-normative responding with age—examining the details of the studies indicates that task equivalency assumptions are not met. In these studies, indicant information of weak diagnosticity is pitted against more reliable statistical base-rate information. Use of the representativeness heuristic (Kahneman & Frederick, 2002; Kahneman & Tversky, 1972) 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. In a more systematic study of the effect of stereotype familiarity in this paradigm, De Neys and Vanderputte (2011) concluded that their findings “support the claim that previously reported age-related performance decreases on classic reasoning tasks need to be attributed to the increased need to deal with tempting heuristics and not to a decrease in analytic thinking skills per se” (p. 1).

How important it is to “drill down” into the specific stimulus characteristics of a developmental study is illustrated in the Morsanyi and Handley (2008) work already discussed above. They reported developmental findings that they argued were inconsistent with dual-processing accounts of reasoning because normative choices became less frequent with development. Of the four different tasks that they studied, the most unambiguous data supporting their claim were those for the “if-only fallacy” problems. If-only thinking refers to the tendency for people to have differential emotive responses to outcomes based on the differences in counterfactual alternative outcomes that might have occurred (Denes-Raj & Epstein, 1994; Epstein, Lipson, Holstein, & Huh, 1992; Miller, Turnbull, & McFarland, 1990). People are more upset at a negative outcome when it is easier to imagine a positive outcome occurring. The if-only effect is present even in situations where the two actual outcomes being compared are identical, when each of the actors being compared has equal responsibility for the outcome, and when the participant is reminded to think rationally about the two situations. The if-only effect represents a failure to decontextualize, because the evaluation of thinking appears to be overwhelmed by what might have happened and thoughts about this counterfactual mask the substantially parallel structures of the two situations and outcomes.

The Morsanyi and Handley (2008) findings were derived from two if-only problems. Their first was as follows:

Tom went camping with his family and he put his bike inside the caravan. His mother told him to put his bike on the roof rack like his sister did, but he didn't listen to her. As luck would have it, Tom's bike got broken. Now listen to the next story. Robert went camping with his family and he put his bike inside the caravan. He had to put it in there because there was a kayak on the roof rack. As luck would have it, Robert's bike got broken. What do you think about the two stories?

- (a) Tom made a worse decision than Robert.
- (b) Robert made a worse decision than Tom.
- (c) It wasn't their fault, it was just bad luck.

Morsanyi and Handley (2008) scored option (c) as the normatively correct choice for this problem, because “neither of the boys made a better decision” (p. 24). But is this unambiguously the case? Examination of the problem itself suggests that scoring option (c) as the normative choice is problematic. Robert apparently did not have the option of storing his bike on the roof rack because there was a kayak already there. In contrast, Tom chose to ignore his mother’s instructions and did not choose the available alternative option of the roof rack. Even if the study’s participants were to make the questionable assumption that Tom’s mother’s instructions provided no additionally useful information about the best place to store the bike, it would still seem to be the case that Robert selected the only practical option available to him. Thus, it is questionable whether or not the two boys’ decisions were equally culpable in the outcome. Alternative (a) is called the heuristic response by Morsanyi and Handley, which we understand to be shorthand for “the non-normative response presumably based on a Type 1 heuristic”. The reason for this piece of pedantry is that *responses* occur at the organismic level and are either normative or non-normative. Heuristics are *subpersonal* processes and are themselves neither normative nor non-normative (see Footnote 3). However, what is called the heuristic here seems to be based on a quite reasonable cultural belief (“listen to your mother”). At the very least, alternative (a) seems as normative as (c), thus rendering developmental trends on this problem theoretically ambiguous.

Morsanyi and Handley’s (2008) second if-only problem was as follows:

Jessica went to a concert with her parents. She asked her father not to take the usual way to the concert hall, but to drive through the city center instead to pick up her friend who lived in the city center and who they promised to take with them to the concert. Unfortunately, they got stuck in a traffic jam and they missed the first 30 minutes of the concert. Linda went to a concert with her parents. She asked her father not to take the usual way to the concert hall, but to drive through the city center instead because she wanted to see the Christmas decorations and lights. Unfortunately, they got stuck in a traffic jam and they missed the first 30 minutes of the concert. What do you think about the two stories?

- (a) Jessica made a worse decision than Linda.
- (b) Linda made a worse decision than Jessica.
- (c) It wasn’t their fault, it was just bad luck.

Once again, Morsanyi and Handley (2008) scored option (c) as the normatively correct choice, and once again, examination of the problem itself suggests that scoring option (c) as the normative choice is problematic. Although both girls chose the route through the city center, their reasons for their choices were quite different. Jessica’s decision was based on a promised ride that both she and her parents had made to her friend who lived in the city center. In contrast, Linda apparently had opted for the unusual route to the concert hall simply because she wanted to see the Christmas decorations and lights. Jessica had the much stronger reason of wanting to fulfill a promise to another person. Once again, it is questionable whether or not the two girls’ decisions were equally regrettable. Alternative (b) was scored as heuristic, but as in the previous problem, it has a normative rule (“always fulfill promises”) in its favor. Both of the problems used in this study have an interpretive ambiguity that is not present in the adult literature that inspired this paradigm (for examples of adult problems, see Stanovich & West, 1998). As used in this experiment, these problems become a case study in how difficult it is to design children’s stimuli that are accurately indicative of the direction of developmental change.

## Conclusion

Our thesis has been that developmental predictions from many dual-process theories are not as obvious as they seem. We have not attempted a comprehensive review, nor have we attempted a new comprehensive presentation of a dual-process theory. Our goal has been much more modest. We wish to draw attention to some of the devilish complexities involved in drawing developmental predictions from many dual-process models. As investigators, we ourselves have been guilty of

thinking that these predictions flowed too easily. Our goal is not innovation, but instead simply to provide a corrective. We have also concentrated on the classic dual-process views that derive from Evans (1984, 1989, 2003) and Tversky and Kahneman (1974; Kahneman, 2000; Kahneman & Frederick, 2002). Some other dual-process views (Brainerd, 2004; Brainerd & Reyna, 2001; Reyna & Brainerd, 1995; Reyna et al., 2003) have been clearer and more accurate in pointing to the fact that their assumptions may yield seemingly counterintuitive predictions.

The drawing of misleading predictions can be avoided by paying attention to several of the cautions we have urged here. The terms normative or rational should be reserved for responses, and not attributed to subpersonal processes. Heuristics (Type 1 processes) are subpersonal processes that can lead to rational or irrational responses. A non-normative response does not necessarily derive from the use of a heuristic, nor does a normative one necessarily derive from Type 2 processing.

The complexity of developmental predictions derives from the fact that overall normative responding at a given age derives from several different mental characteristics: (1) the developmental course of Type 1 processing, (2) the developmental course of Type 2 processing, (3) the acquisition of mindware usable by Type 1 processing, (4) the acquisition of mindware usable by Type 2 processing, and (5) the practicing of the mindware in #4 so that it is available to be processed in a Type 1 manner. The complexity of all these interacting processes and sources of information can sometimes result in U-shaped developmental functions, particularly when the youngest groups are ill-equipped to even understand the task and thus respond randomly. With development, older children may acquire the mindware sufficient to trigger an incorrect short-cut heuristic response to the problem—that is, what might be termed a sophisticated error in the sense that it is more complex than random responding. Only at later stages of development do children acquire the mindware of rational responding that enables Type 2 processing to override Type 1 processing and substitute a more optimal solution. Finally, with additional development and practice, the essence of these rules of rational responding becoming highly compiled and can trigger autonomously—making experts at the problem again appear heuristic, but in a much different sense than they were earlier in the developmental sequence (Brainerd & Reyna, 2001; Kahneman & Klein, 2009).

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