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ABSTRACT

In order to explain the effects found in the heuristics and biases literature, dual-process theories of reasoning claim that human reasoning is of two kinds: Type-1 processing is fast, automatic, and associative, while Type-2 reasoning is slow, controlled, and rule based. If human reasoning is so divided, it would have important consequences for morality, epistemology, and philosophy of mind. Although dual-process theorists have typically argued for their position by way of an inference to the best explanation, they have generally failed to consider alternative hypotheses. Worse still, it is unclear how we might test dual-process theories. In this article, I offer a one-system theory, which I call the Sound-Board Account of Reasoning, according to which there is one reasoning system which is flexible, allowing the properties used to distinguished Type-1 and Type-2 reasoning to cross-cut one another. I empirically distinguish my theory from the two dominant versions of dual-process theory (parallel-competitive and default-interventionist dual-process theory) and argue that my theory's predictions are confirmed over both of these versions of dual-process theory.

1. Introduction

Humans are not perfect reasoners. To varying degrees, they are subject to dozens of heuristics and biases (e.g., fundamental attribution error, base-rate neglect, cognitive miserliness, etc.). Dual-process theories of reasoning explain this data by positing two kinds of reasoning: Type-1 processing is fast, automatic, and associative, while Type-2 reasoning is slow, controlled, and rule based. Philosophers have recognized that if human reasoning is so divided, "then many traditional philosophical questions will need to be recast to allow for this duality, with implications for debates about agency, autonomy, responsibility, rationality and knowledge, among other topics" (Frankish, 2010, p. 923. For application to morality, epistemology, and

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philosophy of mind, see Fiala, Arico, & Nichols, 2011; Frankish, 2016; Mallon & Nichols, 2011; Nagel, 2011). However, dual-process theory is not without its critics. Dual-process theorists have typically argued for their position by way of an inference to the best explanation. However, they have generally failed to consider alternative hypotheses (Osman, 2004). Recently, some dual-process theorists have suggested that the properties typically used to distinguish the two types of systems might cross-cut each other more than was typically thought (see Carruthers, 2013a; Evans & Stanovich, 2013; Mugg, 2015a). We need a one-system account to empirically compare against dual-process theory. However, it is question whether any comparison is possible, since it is unclear how we might test dual-process theories (see Gigerenzer, 2010; Kruglanski, 2013; Kruglanski & Gigerenzer, 2011). A further complication in testing dual-process theory is that "dual-process accounts are a family of theories and … there is no definitive version" (Evans, 2011, p. 87). We can overcome these obstacles by focusing on *specific* accounts of human reasoning, rather than dual-process theories and one-system alternatives in general.

Drawing from Osman (2004), I offer my own one-system theory, which I call the *Sound-Board Account of Reasoning* (S-BAR), according to which there is one reasoning system which is flexible, allowing the properties used to distinguished Type-1 and Type-2 reasoning to cross-cut one another. I argue that we can empirically distinguish my S-BAR from the two dominant versions of dual-process theory (parallel-competitive and default-interventionist dual-process theory). Finally, I argue that S-BAR's predictions are confirmed over both of these versions of dual-process theory.

2. Dual-process theories: Clarifying the dialectic

Dual-process theorists agree that human reasoning is divided into two kinds. Call this the 'Kind Claim'. Generally, dual-process theorists distinguish these kinds by way of a cluster of properties (the 'Standard Menu'). Call this the 'Cluster Kind Claim'. While the exact properties they use differ, they typically agree that Type-1 is fast, heuristic/associative, and automatic (or "autonomous"), and that Type-2 is slow, sequential, and controlled. Thus, dual-process theorists seem to tacitly endorse a homeostatic clustering account of kinds (see Boyd, 1991, 1999). On this suggestion, Type-1 and Type-2 processing, each of which is identified by its own distinct homeostatic clustering of properties, are supposed to constitute cognitive kinds (Samuels, 2009). In response to the claim that these properties cross-cut one another, Evans, Stanovich, and Carruthers have recently rejected the Cluster Kind Claim, suggesting that reasoning is divided using only two

opposing properties. Call this the 'Monothetic Kind Claim' (see Mugg, 2015a for criticism of their novel accounts). Therefore, the Cluster Kind Claim and Monothetic Kind Claim are two ways of spelling out the Kind Claim.

Some dual-process theorists make the further claim that these two kinds are subserved by distinct systems (Carruthers, 2009; Frankish, 2004; Sloman, 1996, 2014). Samuels (2009) helpfully distinguishes between the type and token claims regarding the systems. According to the System Type Claim, there are two kinds of reasoning systems (System 1 and System 2). According to the (stronger) System Token Claim, there is exactly one token System 1 (S1) and one token System 2 (S2). As Samuels (2009) points out, dual-system theorists have tended to endorse a Type Claim regarding S1 and a Token Claim about S2. Thus, we have the following five claims:

Kind Claim. There are two kinds of reasoning processes.

These kinds can be distinguished in one of two ways:

Cluster Kind Claim. The two kinds of reasoning processes are distinguished by homeostatic clusters of properties along the lines of the Standard Menu.

Monothetic Kind Claim. The two kinds of reasoning processes are distinguished using two opposing properties

Orthogonal to the Cluster Kind Claim and Monothetic Kind Claim are:

System Type Claim. There are two kinds of systems that underlie the two kinds of reasoning processes.

System Token Claim. There are exactly two (token) systems, one of each kind.

Given the Kind Claim, we may ask how these processes interact. Dual-process theorists respond in one of two ways, which seem to run orthogonal to the latter-four claims outlined earlier. According to parallel-competitive accounts, the two processes or systems operate simultaneously and are in direct competition with one another. According to default-interventionist accounts, subjects default to Type-1 processes and only sometimes does Type-2 processing modify the Type-1 response.[1] In principle, it seems that all of these distinctions among theories could cross-cut one another. Table 1 shows the conceptual space of dual-process theory.[2]

Table 1. Versions of dual-process theory.

	Default interventionism		Parallel competitive		Monothetic kind claim	Cluster kind claim
	Mere Type	Token	Mere Type	Token		
Dual process	E, E*, St,				E*,	E, St
Two system	Mere Type	Token	Mere Type	Token	C*, St*	C, F, K, Sl
S1	K, St*		C, C*, F	Sl		
S2		K, S*a		C, C*, F, Sl		
Monothetic kind claim	E*, St*		C*			
Cluster kind claim	E, K, S		C, F, Sl			

Key:
Carruthers (pre-2013) = C; Carruthers (post-2013) = C*; Evans (pre-2013) = E; Evans (post-2013) = E*;
  Frankish = F; Kahneman = K; Sloman = Sl; Stanovich (pre-2011) = St; Stanovich (post-2011) = St*
[a]Stanovich (2011) advocates a tripartite division of the mind. What S2 refers to is in fact two systems:
  the algorithmic mind and the reflective mind.

Despite the vast conceptual space possible, theories seem to cluster in certain ways, since some combinations seem unlikely. For example, there may be good reason why there are no parallel-competitive theories of reasoning that deny the System Type Claim. If the two processes are so distinct that they can operate at the same time and compete against one another, then it is plausible that they are carried out by distinct systems, especially if systems defined by the processes they carry out. In Section 4.1, I will build on this claim in order to contrast parallel-competitive theories against one-system theories.

As we will see, these versions of dual-process theory will generate different, sometimes conflicting, predictions. As such, we should not expect there to be any single experiment that counts against dual-process theory *tout court* (Evans & Stanovich, 2013, p. 263). This should not be surprising, since hypothesis testing is contrastive. To see why hypotheses testing is contrastive, consider the classic argument against Popperian falsification: it is always possible to reject one of the auxiliary assumptions used in deducing the (falsified) prediction. If two competing hypotheses share auxiliary assumptions, but differ in prediction, when one of those predictions is false, we must reject one of the difference between the two hypotheses (see Sober (1999) for an extended argument along these lines).

The upshot is that critics of dual-process theory should contrast their alternative accounts against the most plausible versions of dual-process theory. In this article, I do just that. In Section 3, I outline my own one-system account, a recent version of default-interventionism from Evans and Stanovich, and Sloman's version of parallel-competitive theory. In Section 4, I empirically distinguish these theories and offer data in support of my account's predictions.

3. Three competing theories

3.1. *Default-interventionist dual-process theory*

Evans and Stanovich (2013) claim that the distinction between Type-1 and Type-2 processing *is* the distinction between autonomous processing and working-memory involving processing (for similar default-interventionist accounts see Evans, 2010, 2011; Kahenman, 2011; Kahneman & Frederic, 2002; Stanovich, 2011). Evans and Stanovich's account of autonomy closely resembles Fodor's account of automaticity: "the execution of Type 1 processes is mandatory when their triggering stimuli are encountered, and they do not depend on input from high-level control systems" (Stanovich, 2011, p. 19).[3] Stanovich claims that a number of properties will closely correlate with autonomous processes: they will be fast, will not use much executive functioning, and can operate in parallel. Subjects' ability to use their Type-2 reasoning is closely correlated with general intelligence (Stanovich, 1999, 2011) and their working memory capacity (Evans, 2010), which are themselves correlated (Evans & Stanovich, 2013, p. 236).

According to Stanovich and Evans, subjects default to Type-1 processing, which always occurs prior to Type-2 processing (if Type-2 processing even comes online). Subjects are "cognitive misers," in that they will exert as little cognitive energy as possible. Since Type-2 reasoning requires cognitive energy, subjects will avoid using it. However, often correct reasoning[4] requires overriding intuitive (Type-1) responses.

Evans and Stanovich differ slightly over the details of why reasoning errors occur. On Stanovich's tripartite cognitive architecture, there is the autonomous set of systems (TASS) (which engages only in Type-1 processing), the algorithmic mind (which is computational but represents only one state of affairs), and the reflective mind (which engages in novel problem solving, but demands very high amounts of working memory). According to Stanovich, there are three distinct heuristic paths, which accounts for individual differences in reasoning (i.e., why some reply correctly, and others respond in various incorrect ways).[5] In the first two cases, Type-2 reasoning should be engaged, but is not. First, subjects might not have the available mindware required to properly solve the problem. Second, subjects may fail to recognize that they need to override the Type-1 response. Third, subjects might engage Type-2 reasoning, but then fail to override the Type-1 response (see Evans & Stanovich, 2013, p. 268).

Evans (2011) introduces a new model of intervention (called the Intervention Model). What is relevant to my present purposes is that "a new and key feature of the Intervention Model is the idea that Type-2 processing is engaged with a *variable* degree of effort" (p. 95). The amount of working memory available and motivational factors determines how

much working memory a subject uses on a task. Motivational factors include the feeling of rightness of the intuitive response (see Thompson, 2009), individual differences in cognitive style (see Stanovich, 2011), and the kind of instructions given (e.g., subjects are able to resist belief bias in causal reasoning when told to reason deductively instead of pragmatically [Evans, Handley, Neilens, Bacon, & Over, 2010]).

3.2. Parallel-competitive dual-process theory

Sloman claims that there are exactly two token reasoning systems, which he calls intuitive and deliberative (2014, p. 75). Early on, Sloman (1996) claimed that the intuitive system was associative (i.e., connectionist) and the deliberative system was rule based (i.e., computational), but now he claims that there can be intuitive rules (see Osman & Stavy, 2006; Sloman, 2014). The deliberative system operates sequentially, in contrast to the intuitive system. As a result, the intuitive system is much faster (and requires less cognitive energy) than the deliberative system (2014, p. 77). The intuitive system operates fairly autonomously through "positive feedback between intuitive and affective components to relate the body to pattern recognition processes," and the deliberative system operates simultaneously "and serves to modulate the intuitive" (2014, p. 75). Thus, Sloman does not posit a third system that regulates the outputs of the two. Instead, the function that inhibits intuitive outputs is itself part of the deliberative process. However, this inhibition is not always successful. Thus, "deliberation does not always dominate" (2014, p. 75).

According to Sloman's account, subjects fail to respond correctly for one of three reasons: first, the intuitive system gives its output before the deliberative system can finish its processing (which would explain why belief bias increases under time pressure [Evans & Curtis-Holmes, 2005]); second, the deliberative system does generate an output, but is unable to suppress the intuitive response; third, the deliberative system generates an output which is incorrect.

3.3. The one-system theory

Here I will offer my own alternative to dual-process theory. On my account, there is one reasoning system, which can operate consciously or unconsciously, automatically or in a controlled manner (this is a matter of degree), concretely/abstractly (i.e., moving from content-laden argument to attending directly to form of argument), and inductively or deductively.[6] I deny that these properties cluster: the Cluster Kind Claim is false (see Carruthers, 2013a, 2013b; Mugg, 2015a; Evans & Stanovich, 2013, p. 226). For example, the reasoning

system might frequently solve a problem automatically in a rule-based manner (for further examples of cross-cutting, see Carruthers, 2013a; 2013b; Evans, 2008, 2011; Keren & Schul, 2009; Kruglanski & Gigerenzer, 2011; Mugg, 2015a). It should be clear, then, that I am not claiming that there is one reasoning system that operates in a Type-1 way sometimes and a Type-2 way at other times. I am denying all five claims outlined earlier, and therefore my account cannot be placed anywhere on Table 1.

A number of theorists have pointed out that many of the opposing property pairs admit of degrees, rather than being all-or-nothing. For example, a process might be more or less fast, and processes using more or less working-memory are different in degree rather than kind. In this vein, Pim Haselager (2014) suggests that according to dual-process theory, reasoning is like a car that has two gears. Haselager suggests that we need an account of reasoning according to which control is like a car with many gears (though he is unsure whether we need 5 or 500). I agree, and my one-system account will allow for this gradation.[7] Furthermore, subjects might begin solving certain classes of reasoning problems using certain modes, but gradually shift over time, both on a single reasoning problem, and in their (more general) approach to reasoning. Hopefully training in logic enables individuals to utilize better reasoning modes from the start.

On my account, for any reasoning process and any property pair, the reasoning system will operate in a definite way (e.g., it will not operate concretely and abstractly at the same time). Some of the modes, such as concrete/abstract, are on/off in nature: A process is either fully concrete or fully abstract (e.g., attending solely to the form of an argument). On the other hand, some of the distinctions admit of degrees, such as the automatic-controlled distinction. Again, for each reasoning process, the reasoning system will operate in a definitive mode, but here there is a spectrum of levels of control, and so a spectrum of ways of operating. Call the point on the spectrum that the reasoning system operates for a given process the 'mode' of operation.[8] As a way of illustration, we might imagine our reasoning system as an audio mixing board with several switches and slides: one for each property pair. What sound the mixing board outputs for a given sound input depends upon where each of the slides are positioned and which way each switch is flipped. In the same way, the reasoning system's output depends upon its modes of operation. An important question for my one-system hypothesis is when and how the reasoning system changes from mode to mode. This remaining question is analogous to the question for default-interventionism as to how and when a Type-2 response overrides a Type-1 response.

An example of mode switching might help. One important switch is from concrete processing to abstract processing, which involves cognitive

decoupling. A plausible explanation of belief-bias is that subjects are failing to decouple the believed truth of the conclusion from the validity or strength of the argument. A full explanation would require an account of cognitive decoupling as a part of a cognitive architecture of human reasoning. What subjects must do, then, is switch modes from attending to the concrete truth of the conclusion (and often the truth of the premises) to attending to the *form* of the argument or imagine a state of affairs in which the premises are true and the conclusion false. Perhaps an example will help. Consider whether the following syllogism is valid:

1. All whales are mammals.
2. All whales nurse their young.

    Therefore,

3. All mammals nurse their young.

While many subjects will initially judge the argument valid (using concrete processing), a closer inspection reveals that the middle term does not distribute (abstract processing attending to form of the argument), and it is possible to think of a state of affairs in which whales are nursing mammals but some other mammals do not nurse their young (abstract processing decoupling the truth of the conclusion from support for the conclusion).

Mode switching serves a similar function in my account to that which activation of Type-2 processing does in dual-process theory. However, differences remain. Although my account allows for multiple *stages* of processing (e.g., concrete first, then abstract), because these process do not occur simultaneously my account contrasts with parallel-competitive accounts. Because there is no singular kind to which the reasoning system defaults and no set second stage of processing, my account contrasts with default-interventionism as well. The stages of reasoning are too heterogeneous to be called 'kinds' at all. Again, I am denying the Kind Claim.

It would be too cognitively taxing if subjects had to consciously choose which mode they would use for each reasoning task. Worse still, if subjects generally consciously chose which mode they would use, most reasoning processes would lead to a regress. Notice that conscious mode determination is itself a reasoning problem. Thus, the reasoning system would then determine which mode it will use for the mode determination, which is itself a reasoning process. We are off to a regress. We may block the regress by denying that mode determination *must* be actively chosen. Indeed, I think we must deny that the reasoning system alone determines which of the initial modes

it will use in solving a problem. Instead, the reasoning system's mode use is determined by a combination of factors extrinsic to the subject (e.g., setting of test, wording of problem, time allowed for a response, and the most recent mode used) and intrinsic to the subject (e.g., individual thinking dispositions, working memory capacity, interest in problem, and mindware). Individual differences arise as a result of the intrinsic factors.

A subject does not necessarily endorse the initial response that the reasoning system generates. While some details of the reasoning problem might put the reasoning system into certain modes (e.g., the word 'probably' puts it into an inductive mode), the reasoning system can change modes as it works through a problem. For example, if the stakes are high and the subject has time to check his or her answers, the reasoning system may go back over the answer in a way that demands more cognitive resources. While the initial mode determination is not (generally) consciously chosen, conscious mode determination might be more common at this stage. To return to my sound-mixer analogy, the slides and switches all have a definite position when one sits down at the board, but as one listens to the output sound, one alters the slides and switches until the output sound is as desired.

My account bears some resemblance to Osman's (2004) one-system alternative to dual-process theory. Her account is an extension of Cleeremans and Jiménez (2002) dynamic graded continuum theory of learning. On this connectionist account, quality of a representation lies along a continuum and depends on strength, stability, and distinctiveness, where "*strength* is defined as the amount and the level of activation of processing units, … *stability* is the length of time a representation remains active during processing, … [and] d*istinctiveness* refers to the discriminability of representations" (Osman, 2004, p. 993). According to Osman, implicit, automatic, and explicit processing form a continuum. "Implicit reasoning involves making a set of abstractions or inferences without concomitant awareness of them" (p. 995). Subjects usually rely on implicit processing when they encounter novel reasoning problems. "Implicit reasoning is likely to result from situations where reasoners are unfamiliar with the task environment" (p. 996). In contrast to implicit (but not automatic) reasoning, subjects have awareness in *explicit reasoning*, and this awareness "can be expressed as declarative knowledge" (p. 995). Osman claims that explicit reasoning requires metacognition, since it involves thoughts about inferences. Finally, automatic reasoning is "deliberately acquired through frequent and consistent activation of relevant information that becomes highly familiarized" (p. 995). Importantly, subjects do not have control of the inferences, but do possess metaknowledge of them (p. 996). On her account, a procedure for solving a certain kind of

reasoning problem may begin as explicit reasoning, but become automatic over time.

Whereas dual-process theories posit a pair of exhaustive alternatives, Osman's allows for a spectrum between certain opposing properties. Osman posits "implicit" processing and claims that it is on a continuum with the automatic and explicit processing. While I agree with Osman in thinking that implicit and automatic might come apart, contra dual-process theory, since automatic (in Osman's sense) processes do not become implicit over time, it is odd to put these three on a continuum. Thus, it is better to oppose implicit and explicit (which I take to be unconscious and conscious, respectively), on the one hand, and automatic and controlled on the other. The automatic/controlled distinction and the implicit/explicit distinction are both continua, and, though related, are distinct. Dual-process theory posits exactly two kinds of processing. Osman posits exactly one spectrum of reasoning processing. My account posits multiple cross-cutting spectra of reasoning processes.

While many subjects fail to respond correctly in reasoning tasks, some succeed. Furthermore, not all subjects fail the task in the same way (consider that there is no "majority" response in the standard Wason-Selection task). This is what Stanovich (2011) calls 'individual difference', and it is his motivation for a tripartite account of the mind. A rival account of reasoning will need to be able to account for individual difference. Whereas Stanovich uses different ways Type-2 reasoning can fail to override Type-1 responses to account for individual difference, my account relies on differences in mode determination to account for individual difference.

Mode of reasoning determines subjects' responses. Some modes of operation deliver the correct response while other do not. When subjects respond incorrectly, it is because they did not use the correct mode.[9] For example, the reasoning system may operate inductively when a deductive operation would yield the logically correct result. It may operate under its mandatory mode unconsciously, and thus the subject might not check his or her answer.

One way in which subjects become better reasoners is through gaining the ability to put their reasoning systems into the proper mode for each task. One of the most important modes to switch into is the abstract mode, especially in novel circumstances where the subject is not severely limited by time. That is, for generalizable knowledge, subjects who can abstract away from the particulars will be able to reason more in line with full rationality than those who are unable to do so. A necessary condition on switching into abstract reasoning is cognitive decoupling – which Stanovich (2011), Evans and Stanovich (2013), Frankish (2010, 2012), and Carruthers (2006, 2009, 2013a, 2013b) rightly emphasize in their dual-process theories. Minimally, cognitive

decoupling occurs when a subject abstracts away from the details of a problem, especially her own subjective perspective of the problem. Cognitive decoupling allows subject to attend to the *form* of an argument rather than the *content*. Thus, it is essential in properly determining validity of an argument.

4. Competing hypotheses

Because empirical testing is always contrastive, we should develop a hypothesis from parallel-competitive dual-process theory which competes with a hypothesis formed using the one-system theory, and we should develop a hypothesis formed by default-intervention dual-process theory that contrasts with a hypothesis from the one-system theory. In this section, I will develop four such hypotheses and offer empirical support for S-BAR over dual-process theory.

4.1. *Contrasting parallel-competitive dual-process theory and one-system theory*

Sloman provides a clear way to empirically distinguish his account from one-system alternatives. He claims that if a reasoning problem "causes people to simultaneously believe two contradictory responses," then there must be two distinct reasoning systems (1996, p. 11).[10] Sloman does not argue for this claim, but it seems reasonable as a way of distinguishing parallel-competitive two-system theory from some one-system accounts. To see why, consider that two processes that operate in exactly the same way will not differ in their outputs when their inputs are exactly similar. On my account, the reasoning system will always operate in a definitive mode. It might adjust its mode of operation after outputting a response (belief p), rerun the problem, and then alter the response (to believe not-p). However, it will not generate these contradictory responses simultaneously. Thus, if there are contradictory responses, there must be one token process for the output p, and another for the output not-p. Thus, we have the following competing predictions:

One-System Prediction. If the one-system theory is true, then reasoning will not generate contradictory beliefs simultaneously.

Parallel-Competitive Prediction. If the parallel-competitive dual-process theory is true, then reasoning may generate contradictory beliefs simultaneously.

Three points are worth emphasizing. First, notice that I emphasize the simultaneity of the *generation* of the contradictory beliefs. This is because,

on my one-system account, it is possible for the reasoning system to generate belief p at one time and later generate belief not-p, but for the reasoning system to fail to "delete" the belief p (that belief might be implicitly maintained). Second, notice that the parallel-competitive model does not predict that there *will be* conflicting responses for all (or even most) reasoning problems. According to Sloman, generally the reasoning systems generate compatible outputs. Finally, notice that my one-system account predicts a negative existential: "there are no contradictory beliefs generated simultaneously by reasoning." As such, my account's prediction is the null hypothesis. Thus, we should not expect positive evidence for it over the parallel-competitive model.

One might object to my claim that a one-system account is incompatible with simultaneously generated contradictory beliefs by appeal to Spinozan accounts of the mind, according to which whenever a subject considers a proposition, that subject comes to believe that proposition. This is so because acceptance of a proposition is passive and carried out by a distinct system than is responsible for rejecting propositions (see Gilbert, 1991; Huebner, 2009; Mandelbaum, 2014). Thus, on these accounts, when a subject considers whether 'p and not-p', that subject believes p and not-p (though they may subsequently reject that p and not-p) (see Mandelbaum, 2014, p. 76). Spinozan accounts might well be compatible with the simultaneous generation of contradictory beliefs by reasoning, but my prediction here is only meant to be contrastive of *my* one-system account and Sloman's account, neither of which is Spinozan.[11]

Fortuitously, Sloman and I agree on what would be good evidence for parallel-competitive two-system theory. It is important that we also agree on what we take a belief to be. Problematically, Sloman offers an extremely liberal definition of belief, which he does not always abide by: a belief is "a propensity, feeling, or conviction that a response is appropriate even if it is not strong enough to be acted on" (2002, p. 384). Sloman seems to recognize that this definition is too broad, since he wavers over whether subjects continue to believe that the lines in the Müller-Lyer illusion are of different lengths after measuring them. Notice that on his definition, subjects would believe that the lines are different lengths. Rather than offering necessary and sufficient conditions for belief, I will merely note what must be true of beliefs in order for the parallel-competitive model's prediction to be met. Namely, it must be possible for beliefs to be in contradiction with one another. The most plausible way to accomplish this is to adopt a standard representational account of belief according to which beliefs are attitudes toward propositions. Interpretationalist accounts likely rule out the possibility of *simultaneous* contradictory beliefs, since belief attribution is constrained by rationality – if a subject were to believe p, then that subject does not believe not-p. Thus,

interpretationalist accounts are unlikely to be helpful in uncovering the cognitive architecture of human reasoning. However, this should be unsurprising, since interpretationalist accounts tend to draw a sharp boundary between the cognitive and personal level of explanation. I also leave aside nonconceptual content, which may be nonpropositional, since I think it unlikely that nonconceptual content (if such exists) plays a large role in reasoning processing.

Sloman argues that his prediction has been borne out in the heuristics and biases literature. Sloman points to four tasks in which contradictory beliefs are generated simultaneously: category inclusion, argument strength assessment, belief bias in syllogistic reasoning, and the conjunction fallacy. However, while it is clear in these cases that subjects do not always reason according to the norms of rationality, it is unclear why we should think that they believe contradictory beliefs simultaneously (see Mugg, 2013; Osman, 2004). The parallel-competitive theorists must show three things in order for the evidence to count in favor of their prediction:

(1) The beliefs arise from reasoning.[12]
(2) The beliefs are contradictory.
(3) The beliefs are generated simultaneously.

For each task, I grant Sloman the first condition: it is plausible that subjects' responses to these reasoning problems involve reasoning. The problem is demonstrating that conditions 2 and 3 hold. Osman (2004) and Mugg (2013) argue that there is no reason to think that these beliefs are *generated* simultaneously. Consider syllogistic reasoning. Revlin, Leirer, Yopp, and Yopp (1980) asked subject to say what followed from 16 syllogisms. Half were valid, half invalid. Subjects chose between five options (one of which was 'None of the above is proven'). Subjects tended to pick conclusions that accorded with their standing beliefs, even when the premises only supported a weaker conclusion. Sloman interprets this data as showing that "empirical belief obtained fairly directly through associative memory can inhibit the response generated by psycho-logic" (2002, p. 389). However, there is no reason to think that subjects *simultaneously* believed that both the stronger conclusion, which accords with their standing belief, followed and that only the weaker conclusion, which is what actually followed from the premises, followed.

In interpreting some tasks, Mugg (2013) goes even further, arguing that in some of Sloman's cases the beliefs in question are not even contradictory. For example, consider Sloman's argument strength cases. In the experiment Sloman cites (from Osherson, Smith, Wilkie, Lopez, & Shafir, 1990), subjects were given two single-premise arguments and asked to

assess which argument was stronger. Each argument had the following form:

Argument 1
Robins have an ulnar artery.
Therefore, birds have an ulnar artery.
Argument 2
Robins have an ulnar artery.
Therefore, ostriches have an ulnar artery.

Most said that Argument 1 was stronger, but if all birds have an ulnar artery, then so do all ostriches (since ostriches are birds). In exit interviews, subjects admitted that Argument 2 must be at least as strong as Argument 1, though they maintained that their initial claim (that Argument 1 is stronger) is reasonable.

It is plausible that subjects are interpreting these claims as generics, which are statements that express generalizations lacking explicit quantifiers (i.e., 'all' or 'some').[13] Generics are sensitive to non-quantitative content-based factors, especially striking features (consider the generic 'ticks carry Lyme disease'). Importantly, when a claim such as 'ducks lay eggs' is interpreted as a generic, the existence of a duck that does not lay eggs does not falsify the claim, nor does it being the case that most ducks do not lay eggs falsify the claim. (Only a minority of ducks lay eggs, since half are male and therefore do not lay eggs, and some females are sterile or too young to lay eggs.) Sarah-Jane Leslie (2007, 2008) found that when subjects were told that a novel animal, 'lorches', sometimes has purple feathers which (in rare cases) are poisonous, subjects tended to affirm the claim that 'lorches have poisonous feathers'. 'Bird have an ulnary artery' has different truth conditions when interpreted as a generic (closely tied to normalcy), than it does when interpreted as a universal (as Sloman assumes subjects are interpreting it). 'Bird have an ulnary artery' would not be falsified by ostriches' lacking ulnary arteries, especially since ostriches are not normal birds. If subjects are interpreting the propositions in Arguments 1 and 2 as generics, then Argument 1 may be stronger than Argument 2.

Importantly, Leslie has argued that subjects default to generic interpretations (2012, p. 33). Her argument is an inference to the best explanation. First, no known language has a word that signals generics (unlike existential and universal quantification). Second, generalization using generics develops early in ontology, before existential or universal quantification. Hollander, Gelman, and Star (2002) found that 3-year-olds responding to yes/no questions about kinds did not take into account whether the question was about an existential, universal, or generic claim. Their responses indicated that they were interpreting all claims as generics.

This phenomenon is not specific to English speakers (see Tardif, Gelman, Fu, & Zhu, 2012).

The upshot is that it is plausible that subjects interpreted the sentences in Osherson and colleagues as generics rather than universals. Sloman might point out that subjects admitted, in exit interviews, that there was good reason to think that Argument 2 must be at least as strong as Argument 1 (since ostriches are a kind of bird). Notice that this only follows when the propositions in arguments are universally quantified. Subjects can admit that there is good reason to think that Argument 2 is at least as strong as Argument 1 (when the propositions are interpreted as universals) and that there is good reason to think that Argument 1 is stronger than Argument 2 (when the propositions are interpreted as generics). We should not expect subject to be able to articulate this distinction. After all, English lacks a word to signal generics. Thus, there is no reason to think that subjects hold contradictory beliefs that were generated simultaneously by reasoning.

De Neys has recently provided experimental evidence that model biased reasoners are not wholly ignorant of their bias. De Neys's evidence for this is that even biased reasoners, on average, take longer to respond to conflict cases (e.g., valid argument/unbelievable conclusion) than congruent cases (valid argument/believable conclusion) (De Neys, 2012, 2014; De Neys & Glumicic, 2008). De Neys argues that conflict cases cue a heuristic intuition, in keeping with both default-interventionist and parallel-competitive dual-process theory, but that there is also a Type-1 generated "logical intuition." He has suggested (personal correspondence) that logical intuitions lend support to the claim that people do hold contradictory beliefs simultaneously.

What De Neys calls "logical intuitions" would only confirm parallel-competitive dual-process theory over my one-system account if logical intuitions were reasoning-generated beliefs. To my knowledge, De Neys has never claimed that logical intuitions are full-blown beliefs. Two points to note. First, even if logical intuitions are beliefs, such that humans have contradictory beliefs generated simultaneously by reasoning, the divide in systems would not be between System 1 and System 2, but rather between two fast and automatic reasoning systems, such as two members of Stanovich's TASS (the autonomous set of systems). Second, it is not at all clear that the data support the existence of contradictory *beliefs*. De Neys and his colleagues have focused on response times and confidence ratings. This is evidence that subjects are processing information. These results may be from subjects weighing evidence that pulls in opposite directions.[14]

Furthermore, some of De Neys' most recent work might actually problematize the idea that his results should be explained in terms of

contradictory beliefs generated simultaneously. His "conflict detection studies are always run at the group level" (2018, p. 59). Thus, his studies suggest that "the 'average' biased reasoner" is not wholly ignorant of his or her error, but "this does not imply that every single individual in the group shows this effect" (2018, p. 59). How can we tell if no individuals are blind to their error? De Neys ([2018](#)) explains how he and his colleagues are working to answer this question:

> We tackle this problem by co-registering different conflict detection measures. If an individual constantly shows detection effects across different measures (e.g., show both more doubt *and* longer latencies on conflict problems), we are more certain that the effect does not result from chance or a measurement error. Our initial results show that the majority of biased reasoners indeed consistently show conflict detection effects across multiple measures (Frey, Johnson, & De Neys, [2017](#)). However, we also find that … up to 15% of biased reasoners … consistently fail to show any detection effects. (p. 59).

That some reasoners *are* blind to their bias, whereas some are not, is surprising if there are two simultaneously competing Type-1 processes (one issuing a heuristic intuition the other a logical intuition) that both issue automatically. If these are beliefs formed automatically by simultaneously operating (Type-1) reasoning processes, we should expect all subjects to issue both responses. Perhaps subjects are engaged in very fast serial reasoning operations instead. Subjects De Neys classified as biased-but-not-wholly-ignorant engaged in two reasoning processes, one right after another. That is why those reasoners took longer to respond.

If we do not have evidence for the existence of contradictory beliefs generated simultaneously by reasoning, S-BAR is confirmed over parallel-competitive dual-process theory. While Sloman ([1996](#), [2002](#)) offers some cases for the existence of such beliefs, I have responded that there is no reason to think that they are maintained simultaneously. While Sloman might marshal experimental evidence from De Neys, I have argued that we would be too quick in accepting the responses as beliefs and that there is now doubt that they are generated simultaneously. Admittedly, it is possible that we will find evidence for contradictory beliefs that are generated by reasoning simultaneously in the future: S-BAR predicts a negative existential whereas parallel-competitive dual-process theory predicts a positive existential, and negative existential are notoriously difficult to demonstrate by empirical methods. I think something more positive can be said when we compare the one-system account to default-interventionism.

4.2. Contrasting default-interventionist dual-process theory and one-system theory

It is unclear whether default-interventionism is compatible with the existence of contradictory beliefs arising from simultaneously operating reasoning process. It seems Evans and Stanovich should reject the possibility of such beliefs, since Type-2 processes *replace* Type-1 responses rather than competing against them. One implication is that contradictory beliefs arising from simultaneously operating reasoning processes can empirically distinguish parallel-competitive and default-interventionist dual-process theories, and, consequently, default interventionists are wrong to cite Sloman (1996, 2002) as supporting their cognitive architecture. A second implication is that default interventionism and one-system alternatives must be empirically distinguished on other grounds. Recall that Evans and Stanovich's versions of default interventionism takes automaticity and working-memory involving as the crucial contrastive properties distinguishing Type-1 and Type-2 processes.[15] After outlining some differences in prediction, I argue that work on reasoning and working-memory confirms predictions generated by my theory over default interventionism.

It has long been clear that loading working memory during reasoning tasks decreases reasoning accuracy (see, e.g., Gilhooly, Logie, Wetherick, & Wynn, 1993). How much working memory do subjects need to complete a reasoning task in a mode that will render the normatively correct response? According to Stanovich and Evans (2013), there are two kinds of reasoning processes: those that are mandatory (or "autonomous," as they call them)[16] and those that involve working memory. That is, they posit two modes of control. Thus, for any given reasoning task, we should expect subjects to use one of the two levels of control. However, on my account, I allow for a gradation. There are not two modes of use of working memory, but a smooth gradation. Subjects can use more or less of their working memory in various tasks. On my sound-mixer analogy, automatic/controlled processing is a slide, not a switch, on the mixing board.

These theoretical differences lead to two different predictions concerning interference formation under cognitive load. We know that putting a load on working-memory increases many biases, especially belief bias (see, e.g., Evans & Curtis-Holmes, 2005). Of course, the amount of load on working-memory is not all-or-nothing. Researchers can put greater and lesser cognitive load on subjects. Default-interventionism predicts a threshold where the working-memory load becomes too great for subjects to engage in Type-2 reasoning. Where this threshold lies will vary from individual to individual depending on their thinking dispositions and working memory capacity. At this threshold, subjects are forced to use

only their Type-1 processing – Type-2 processing will fail to intervene. To use Stanovich's taxonomy for individual differences in reasoning errors, even subjects who avoid the first two heuristic paths will end up taking the third heuristic path. Thus, as researchers increase load on working memory, there should be a jump at some point in reasoning errors. The jump will occur at the point where working memory load is high enough to prevent subjects from using their Type-2 reasoning for the purpose of solving the reasoning tasks at hand, that is, at the point where subjects can, at best, use heuristic path 3. Notice that since Type-1 processing does not use working memory, adding additional load on working memory after this threshold should not increase reasoning errors. Thus, Stanovich and Evans's accounts predict that the relation between the amount of reasoning errors and the load on working memory will resemble a sigmoid function (see Figure 1).

If there is only one reasoning system that can operate more or less automatically or in a controlled manner and uses more or less working memory, then there should be a smooth relation between load on working memory and reasoning errors. Thus, my account predicts no threshold as the default interventionist does. If my account is right, then the relation between cognitive load and reasoning errors is not expressed by a sigmoid function.

One might object to these predictions on grounds that greater control does not necessarily imply better reasoning. However, there are some reasoning problems for which greater control is closely correlated with better reasoning. Specifically, correctly responding to syllogistic reasoning tasks generally requires working memory. We know this because we know
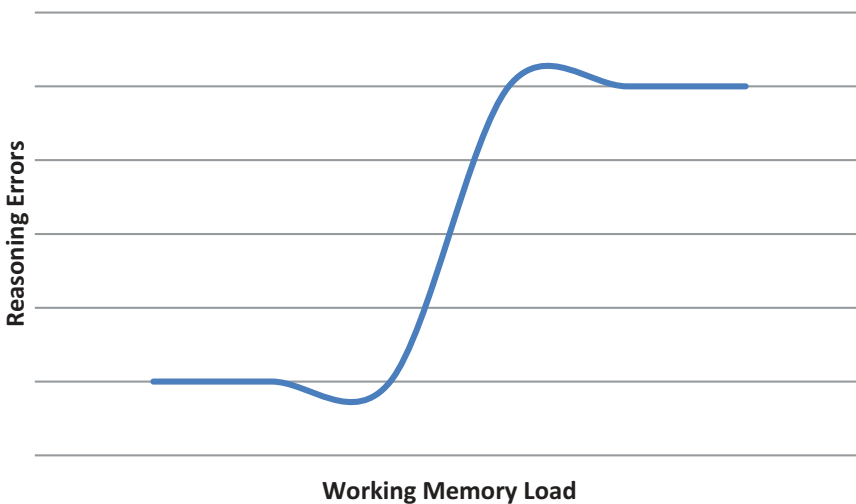

Figure 1. Prediction on default-interventionism.

that increased cognitive load increases belief bias (Evans & Curtis-Holmes, 2005).

Empirical research on working memory and syllogisms favors my prediction. Much work in this area has concerned empirically testing mental models accounts of reasoning (especially Johnson-Laird, 1983) from heuristic models (such as Chater & Oaksford, 1999). The connection between working memory has been tested in two ways. First, dual-tasks require subjects to engage in some activity requiring working memory (e.g., tapping a foot, repeating '1, 2, 3, 4, 5', or having to randomly say these numbers, as in Gilhooly et al., 1993; Gilhooly, Logie, & Wynn, 2003). Second, experimenters compare working memory captivity (as determined by OSPAN and other tests) to reasoning accuracy (Copeland & Radvansky, 2004). One study by De Neys (2006) combined both of these methods. De Neys tested individuals under three conditions: no load on working memory, medium load on working memory, and high load on working memory. He used a dot memory task for the medium and high loads put on working memory (see Figure 2). In the no load condition, subjects were not required to memorize anything. Subjects then assessed the validity of four syllogisms. As predicted by the one-system theory, "performance decreased *linearly* with increasing secondary-task load" (p. 431, emphasis added) (see Figure 3). De Neys only takes this to indicate that proper reasoning in conflict cases requires "executive working memory resources" (p. 431).[17]

Admittedly, De Neys (2006) only tested subjects under three levels of cognitive load. My case would be stronger if we saw this linear correlation between reasoning errors and many degrees of load on working memory. However, De Neys' findings are consistent with other work on working memory and syllogistic reasoning, such as Copeland and Radvansky (2004), who found linear correlations between working memory capacity and correct reasoning.
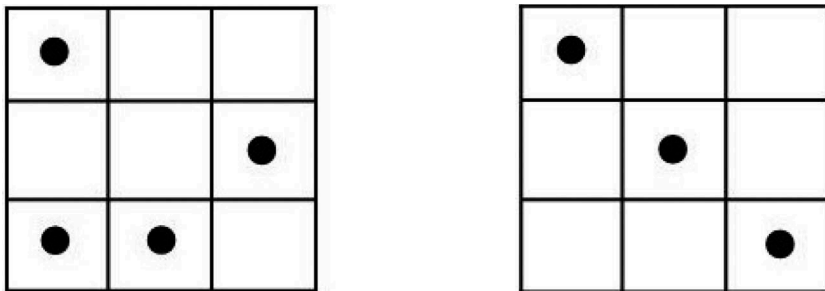
Figure 2. Example of high and low interference in De Neys (2006). High interference (left). Low interference (right).
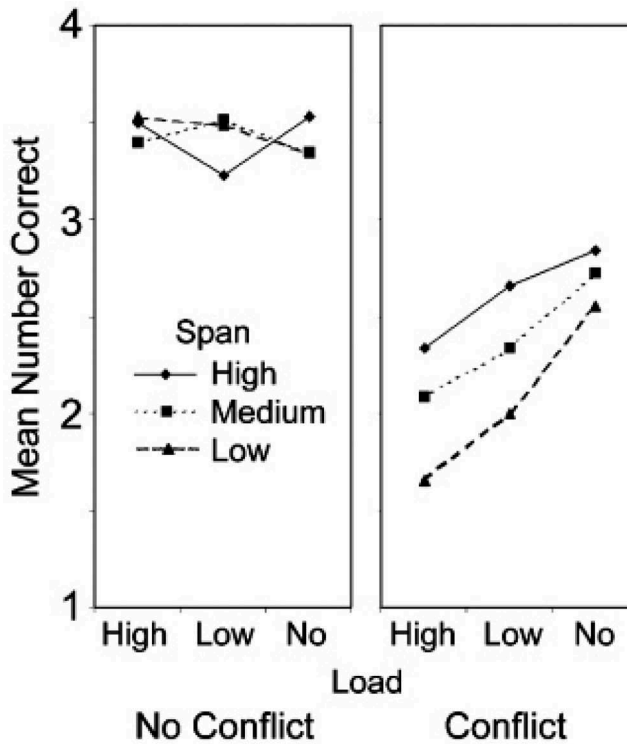
Figure 3. The relation between cognitive load and reasoning errors (from De Neys, 2006).

Stanovich might reply that subjects in the medium cognitive load condition used their algorithmic mind while those under no cognitive load used their reflective mind. Recall that the algorithmic mind and reflective mind both engage in Type-2 reasoning, but the algorithmic mind uses (generally) far less working memory than the reflective mind. On Stanovich's account, we might expect two steps in the graph instead of one – Type-1 reasoning involves no working memory, Type-2 reasoning as carried out by the algorithmic mind involves a certain degree of working memory, and Type-2 reasoning as carried out by the reflective mind involves a yet greater degree of working memory.

There are some problems with this proposal. First, the algorithmic mind is of no help whatsoever if the appropriate mindware is not available. That is, unless subjects have been trained in logic, they must either use their reflective mind or use Type-1 processing. However, in De Neys (2006), the subjects were syllogistically naïve. Thus, they would either be forced into reflective thinking or Type-1 thinking. Therefore, Stanovich's theory should predict that there would be a single threshold. There is a second problem for Stanovich, even if subjects were able to use their algorithmic minds. De Neys divided subjects into three groups according to their

working memory capacity. We should expect that the threshold for switching to Type-1 processing varies with working memory capacity. As such, the low-capacity subjects should have a lower threshold than the high-capacity subjects, and the medium-capacity subjects should have something in between (see Figure 4). However, this alternative prediction is not consistent with the results in De Neys (2006). We do not find each group (high, medium, and low working-memory capacity) differing in their "switching point." Rather, each group's reasoning errors increased under similar load conditions. These findings strongly suggest that there are not three levels of working-memory involvement, the switching points of which vary by individual.

Some of Evans' work suggests that the amount of working memory used in a process will vary in degree (2009, 2011). Evans posits a process wherein subjects decide how much cognitive energy they will use in a given reasoning problem (in 2009 he calls this "Type- 3" processing, but he later drops this terminology). Before engaging in a reasoning task, subjects must determine how much cognitive energy they will devote to a given reasoning problem, and Evans suggests that this determination itself is made by Type-2 reasoning. However, the determination of how much working-memory to use on a reasoning problem is itself a reasoning process, since the deliberation as to how much cognitive energy one should use is determined by Type-2 processing, which is (by hypothesis) reasoning. Since the determination of how much cognitive energy one will expend is itself a reasoning process, there will have to be a further process to determine how much cognitive energy the subject will devote to it.
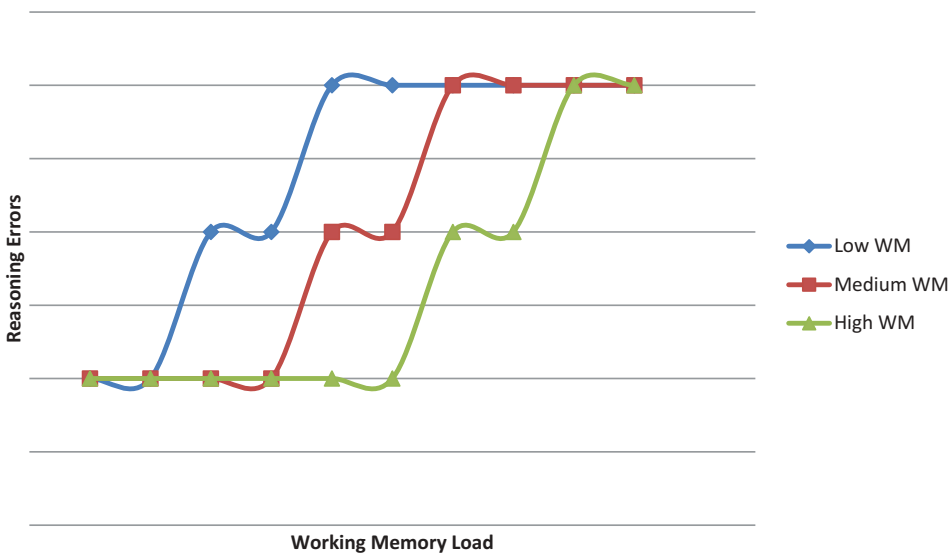
Figure 4. Amended prediction on default-interventionism.

Thus, we have the same regress that my account faced. Whereas I avoid the regress by claiming that the initial mode determination is made without reasoning (instead by external and internal factors), Evans claims that *reasoning itself* determines how much working memory to use. This is a deep flaw in Evans' attempt to allow for differences in degree of working memory involvement.[18] While Evans might want to make his account compatible with a spectrum of working memory involvement, he has failed explain how this is possible on his account.

Suppose that Stanovich and Evans' accounts are compatible with Type-2 processing using various amounts of working memory. On this suggestion, in the medium load on working memory conditions, subjects might be able to use their Type-2 processing, but not as fully as those who have no load on working memory. Furthermore, Type-2 reasoning might have many degrees of control. Thus, the reply concludes, dual-process theory is compatible with a graded relation between load on working memory and syllogistic reasoning errors.

The above reply is consistent with the data, but threatens to strip default-interventionism of its substantial claims. Suppose Type-2 processing can use more or less working memory. Now, if reasoning processes are to be distinguished into kinds by the amount of working memory they involve, then it would seem that Type-2 reasoning will likely be split into more types. We will need a type of reasoning for medium use of working memory, another for high use of working memory, and perhaps many more in-between. The worry here is that default-interventionism must admit many kinds of reasoning processes. Evans and Stanovich might reply that there is a qualitative distinction between involving *no* working memory and involving *some* working memory (even if it is very little), but there is only a quantitative difference between using *very little* working memory and using *a lot* of working memory. The problem with this suggestion is that it trivializes default-interventionism. Any view of the mind that posits working memory (but which does not claim that working memory is required for every reasoning task) would then be committed to the Kind Claim.

5. Conclusion

In response to the mounting problems dual-process theory faces, we need to consider alternative cognitive architectures of human reasoning. In this article, I have offered one such alternative account: the S-BAR. Rather than comparing my account of human reasoning against a "general" dual-process theory, I have empirically contrasted it with what I take the be the best versions of parallel-competitive and default-interventionist theory.

I have argued that there is a lack of evidence for parallel-competitive dual-process theory's hypothesis as compared to my one-system hypothesis. I have argued that my account's predictions are better confirmed by data from De Neys (2006) than default-interventionism. Human reasoning is not divided in two as dual-process theorists argue; the data better confirms the Sound-Board Account of Reasoning.

Notes

1. Smith and Collins (2009) say that the distinction between default-interventionist and parallel-competitive models is not "clear cut" (p. 205). Mugg (2015b) argues that the distinction should be seen on a continuum between one-system and parallel-competitive theories, with default-interventionism occupying a middle position.
2. Actually, things are even more complicated, since some of these theorists claim that humans possess two minds (Evans, 2010; Frankish, 2004; Stanovich, 2011) while others maintain that the two kinds of processing occur within one mind (Carruthers, 2009; De Neys, 2006; Sloman, 1996, 2014). When we take into account that each of the versions of dual-process theory might be combined with either a one or two mind theory, there are 28 possible versions of dual-process theory. There are, of course, more, since exactly how the two systems/processes compete or intervene may differ from theory to theory, and among monothetic accounts there are many property pairs that one could use to distinguish the two kinds of processes/systems.
3. For a helpful discussion on the nature of automaticity (or "mandatory"), see Mandelbaum (2015).
4. By 'correct reasoning' I mean reasoning that accords with the norms of logic.
5. Note that heuristic reasoning is often normatively correct and Type-2 reasoning can be incorrect (see Evans & Stanovich, 2013 p. 264).
6. Some other properties on the Standard Menu constrain these properties (e.g., amount of working memory required) and others depend on these properties (e.g., the speed of a process depends upon which mode is used). Dual-process theorists would call the inductive/deductive distinction a difference in "thinking style" and might subsume both under Type-2 processing. However, since on my account there is no Type-1/Type-2 processing to be had, there is no problem in positing the inductive/deductive distinction alongside the distinctions on the Standard Menu.
7. Exactly how many degrees of control there are, and whether they are analog or digital, is an empirical question which I will not take up here.
8. Some dual-process theorists contrast 'mode' with 'property.' The latter is supposed to mark a distinction in kind (between Type-1 and Type-2 processing) while the former admits of degree (and is only present within Type-2 processing). My intended meaning follows the traditional metaphysical sense: modes are properties. A mode of an object is a way that the object is. A mode of a reasoning process is a way that the reasoning system is. In this case, the modes I have in mind are the ways in which the reasoning system operates.
9. Notice that unconscious or inductive reasoning may produce a correct response even if suboptimal in certain cases. So my claim is not tautological.

10. On Parallel-Competitive dual-process theory, even though the two processes start at the same time, a Type-1 process will finish before a Type-2 process. The beliefs are generated at the same time in that the processes begin and operate at the same time.

11. One might claim that Sloman's account is Spinozan. Mandelbaum (2014) makes it clear that his account is to be contrasted with dual-process theory.

12. This condition is needed because in some optical illusions (such as the Muller-Lyer illusion) the contradictory responses arise from two different kinds of processing (one perceptual, the other cognitive). Such accounts should not count as evidence for dual-process theory.

13. Mugg (2013) makes this suggestion, but does not discuss it in detail.

14. w?>What logical intuitions are (if they exist), and whether they are beliefs, is as much a conceptual question as it is an empirical one. This discussion cannot be divorced from a more complete metaphysics of belief. While accommodating De Neys and his colleagues' finding will be important in defining belief, that task lies beyond the scope of this article.

15. While I focus on Evans and Stanovich (2013) in this section, my way of distinguishing default-interventionist dual-process theory from one-system theory applies equally to any account that takes automaticity and working memory involving as central to the Type-1/Type-2 or S1/S2 distinctions.

16. One might object to Evans and Stanovich's contrasting mandatory with working memory involving on grounds that they are not mutually exclusive categories. For the sake of argument, I will assume that autonomous processes do not involve working memory.

17. De Neys is a dual-process theorist, and interprets these results within a dual-process framework. However, he only claims that the results are *consistent* with dual-process theory without considering how a one-system theory might explain these results. Once we see hypothesis testing as necessarily *contrastive*, we can better appreciate the importance of his findings.

18. De Neys (2012, 2014) has attempted to resolve the regress for DPT. According to De Neys, subjects possess "logical intuitions" alongside "heuristic intuitions." Typical biased reasoners are aware, on some level, that their response is not right. "If the intuitive system cues both a logical and heuristic response, potential conflict can be detected without prior engagement of the deliberate system" because the conflict arises after type-1 processing alone (2012, p. 34). If there is no conflict, the reasoning process ends, but "any conflict between the two responses would signal the need to engage the deliberate system," though the deliberate system is not guaranteed to be "successfully recruited or completed" (2012, p. 34). However, the problem remains: what is monitoring whether there is a conflict or not? A type-2 process carried out by the deliberative system? Clearly not, since the deliberative system would not yet be activated.

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Notes on contributor

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