

The ‘whys’ and ‘whens’ of individual differences in thinking biases

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Although human thinking is often biased, some individuals are less susceptible to biases than others. These individual differences have been at the forefront of thinking research for more than a decade. We organize the literature in three key accounts (storage, monitoring, and inhibition failure) and propose that a critical but overlooked question concerns the time point at which individual variance arises: do biased and unbiased reasoners take different paths early on in the reasoning process or is the observed variance late to arise? We discuss how this focus on the ‘whens’ suggests that individual differences in thinking biases are less profound than traditionally assumed, in the sense that they might typically arise at a later stage of the reasoning process.

Introduction

Since the 1960s, a myriad of studies in the cognitive sciences have demonstrated biases in human thinking – that is, systematic and predictable deviations from formal norms, such as the laws of logic, the theory of probability, or the axioms of rational choice [1,2]. In general, people have been shown to have a strong tendency to base their judgments on fast intuitive impressions [1]. Although this intuitive or so-called ‘heuristic’ thinking can sometimes be useful, it can also cue responses that conflict with formal norms and bias people’s reasoning [1,3,4]. Most individuals display these thinking biases, but people show substantial and consistent differences in their propensity to do so. These individual differences have been at the forefront of thinking and reasoning research for more than a decade [4,5].

Cognitive scientists have proposed numerous answers to the question of why some individuals tend to produce biased responses, whereas others do not. In this article, we offer two perspectives on how to organize this literature. In a first section, we organize current research into three key positions, which assign different cognitive loci to thinking biases (storage failure, monitoring failure, inhibition failure). In a second section, we introduce a different, albeit closely related, organization of the literature. We suggest that, instead of focusing on why individuals differ, we may

consider when they start to differ in the reasoning process. Although these two questions are highly intricate, we will suggest that they bring two equally useful perspectives on outstanding questions in thinking biases research. We will conclude, in particular, that considering the ‘whens’ of individual differences in thinking biases make these differences appear less profound than what their ‘whys’ would suggest. That is, individual differences in reasoning may typically arise at a late stage of the reasoning process, up until which all reasoners follow the same cognitive path.

The ‘whys’

Quite naturally, 50 years of research into thinking biases have resulted in an overwhelming variety of views and interpretations about their nature and cause [6–9]. Our goal here is to develop an overview of the key positions in this debate, rather than to provide an exhaustive taxonomy. We link these key positions to three elementary components of the reasoning process (Figure 1, top panel). In very general terms, one can argue that reasoning is based on at least three building blocks: storage, monitoring, and inhibition [6,10,11]. Biased thinking can result from a failure in each of these components. Accordingly, and in a very similar fashion to previous syntheses [12], we will use this framing device to introduce the main positions in the thinking biases debate: storage failure, monitoring failure, and inhibition failure. (See Box 1 for a fourth and quite distinct ‘alternative norm’ view.)

Note that this partition is used as a coarse-grained framing device, rather than a specific, mechanistic theory of bias and reasoning. A specific theory would have to introduce many fine-grained distinctions between different subtypes of storage, monitoring, and inhibition failures. Note also that our overview focuses on the ‘modal’ biased reasoner. That is, the accounts we survey are meant to explain the typical nature of a biased response, as given by the majority of biased reasoners. This does not entail that different reasoners cannot be biased for different reasons or that the same reasoner is always biased for the same reasons. Obviously, the locus of individual differences need not be fixed and can be contingent on specific task, context, person, or developmental factors [12]. To summarize, we offer in the next section a coarse grained partition of the cognitive processes in which may reside the modal locus of reasoning biases.

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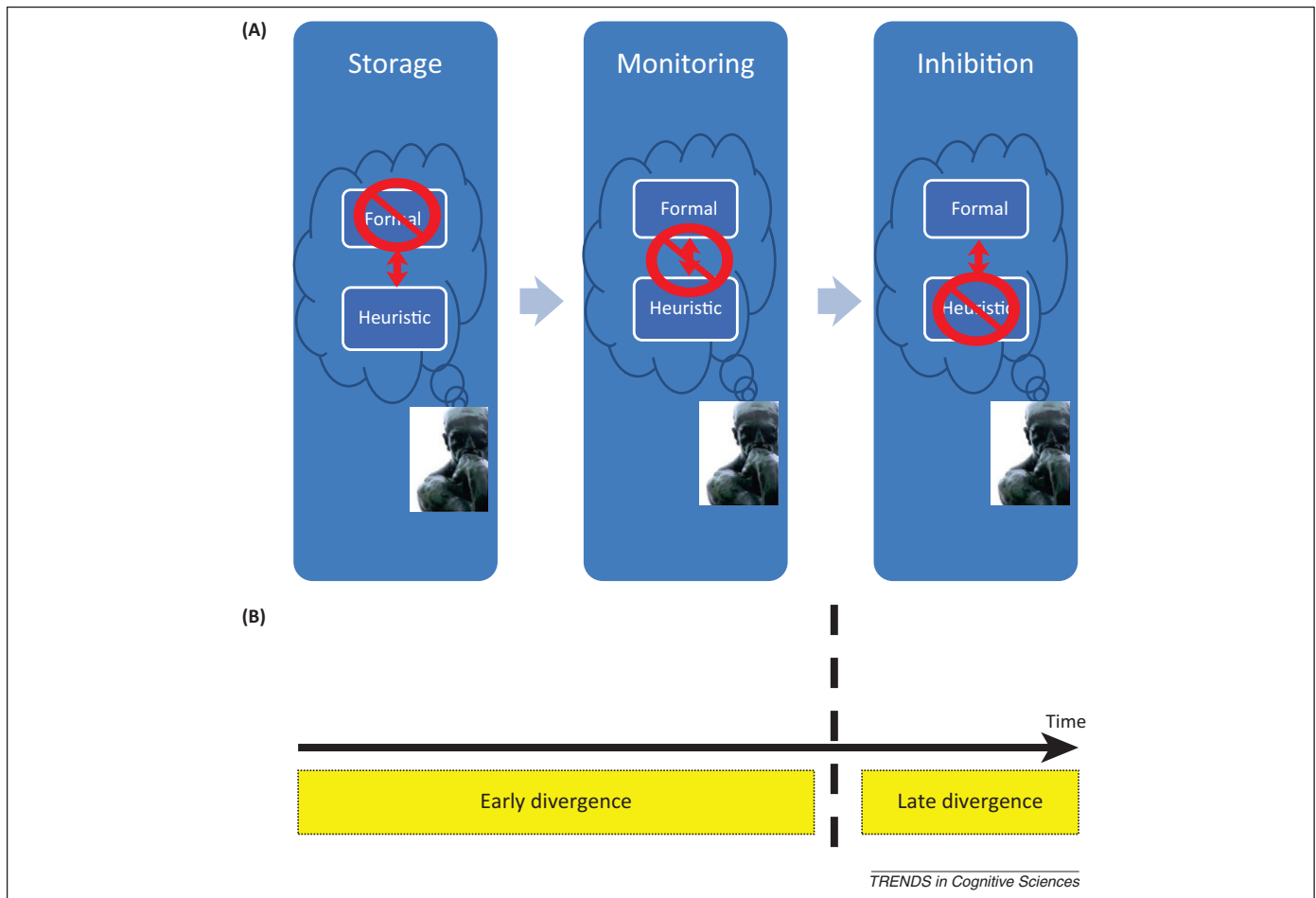


Figure 1. Framing the 'whys' and 'whens' of individual divergence. **(A)** Bias and the resulting divergence between biased and unbiased reasoners can result from a failure in each of at least three elementary components of the reasoning process: storage, monitoring, and inhibition. Key positions in the bias debate differ as to which of these components is considered the major source of bias. The storage failure account entails that biased reasoners have not stored the necessary formal knowledge. The monitoring failure account entails that biased reasoners do not use this knowledge and fail to detect conflict between stored formal knowledge and an intuitively cued heuristic response. The inhibition failure account entails that biased reasoners detect this conflict but consequently fail to inhibit the heuristic response. **(B)** The elementary components can be ordered on a time line (from early to late in the reasoning process). Accounts that posit a storage or detection failure entail an early divergence point where biased and unbiased reasoners are bound to take a different route from the start. The inhibition failure account favors a late divergence, where reasoners only start to diverge in the later stages of the reasoning process downstream from the detection component.

Storage failure

Under the storage failure account, bias is attributed to a lack of formal knowledge. The fact that one gives an incorrect response is simply taken to imply that one did not know the correct response. This account zeroes in on the point that one must be acquainted with the laws of logic or probability in order to compute a response that abides by these laws – and if a reasoner is not in possession of such a knowledge base (or such 'mindware', e.g., [6]), this reasoner cannot produce a normatively correct response. Consequently, individual differences in thinking biases can be attributed to individual differences in stored formal knowledge. Historically, the storage failure account can be traced back to the classic works of Piaget [13] and Wason [14]. Although few contemporary authors hold this general view, storage failure is still a popular explanation for specific biases [6,15].

Monitoring failure

Under the monitoring failure account, bias does not result from a lack of appropriate formal knowledge, but rather from a failure to draw on this knowledge when it is needed. Proponents of the monitoring failure view have focused on

the fact that, although intuitive heuristic thinking can bias people's judgments, it is nevertheless valuable [16]. In a lot of situations, heuristic intuitions can cue solutions that reside with formal norms. Because heuristic thinking is believed to be fast and effortless, it is considered to be very useful in these cases [1,3]. The problem is that people's intuition can also cue formally incorrect responses. Hence, in order to avoid bias one needs to monitor one's heuristic response for conflict with stored formal knowledge. In case such a conflict is detected, one will need to override the heuristic response [5,11]. The key point of the monitoring failure account is that most people are bad at monitoring and will consequently not notice that their heuristic answer needs to be corrected [1,17]. Hence, because not all thinkers succeed in detecting potential conflicts, some of them display thinking biases.

Note that the failure at monitoring reasoning and detecting conflicts can result either from insufficient executive resources or from a dispositional or motivational aversion to engage in cognitively demanding tasks [4]. Hence, under the monitoring failure account, it is not necessarily the case that biased responses would reflect

Box 1. Alternative norms*'Biased' or 'alternate-norm' responses?*

When we refer to a response as 'unbiased' in this article, we mean that it is considered as correct by normative frameworks, such as the laws of standard logic, the theory of probability, or the axioms of rational choice. This is in itself a point of contention [32–34]. According to the alternative norms account of thinking biases, responses to classic reasoning and decision-making tasks are simply measured against the wrong standards. Consequently, they should not be labelled as 'biased', let alone 'incorrect', when they do not correspond to these ill-chosen standards, as long as they comply with other reasonable norms. For example, popular suggestions for alternative norms include Bayesian computations [32], nonclassical forms of logic [35–38], and the pragmatic rules that govern people's conversational exchanges [33,39].

The cognitive locus of alternate-norm responses

The alternate-norm view is somewhat orthogonal to the three accounts we consider in the main text. It is compatible with the storage failure account, in the sense that reasoners may produce the alternate-norm response, while not possessing the formal knowledge that would be required for producing the classic-norm response. It is compatible with the monitoring failure account, in the sense that reasoners may produce the alternate-norm response without even trying to monitor for conflict with the classic-norm response. In this case, the reason for monitoring failure would not be a lack of cognitive resources or motivation, but the perceived irrelevance of the classic norms. Finally, just as in the inhibition failure account, reasoners might possess knowledge about classic norms, detect the conflict between classic and alternate norms, but not inhibit the alternate-norm response, because they are in doubt as to which norm they should adhere to [23,40].

cognitive limitations. Biased thinkers might well have abundant cognitive resources, but not be motivated to allocate them to the reasoning process. In any case, monitoring failure can explain why people who have the right mindware produce a biased response: they never detected that the use of this mindware might be appropriate in the situation. Typical evidence for this view comes from think-aloud or justification protocols, in which biased reasoners very rarely refer to formal principles or feelings of conflicts [16,18,19].

Inhibition failure

Under the inhibition failure account, reasoners do have and use formal knowledge. The key defining feature of this

account is the assumption that reasoners easily monitor reasoning for potential conflicts between stored formal knowledge and heuristic intuitions. This does not necessarily entail that they have a fully explicit understanding of the relevant formal principles: the formal knowledge that allows people to detect a conflict is often conceived to be implicit in nature [20–25]. The key point is that this implicit knowledge suffices to signal a potential conflict with the intuitive response. Accordingly, all reasoners receive this signal and the reason why some of them still produce a biased response is that they fail to inhibit their intuitive response and to override it with a formal response.

The cause of this inhibition failure is open to different interpretations. One possibility is that biased thinkers would lack the necessary motivational and/or cognitive resources required to complete a demanding inhibition process [18,26,27]. Another possibility is that an intuitive heuristic response can only be overridden when the implicit signal of conflict is followed by a more deliberate reflection and the production of an explicit justification for the questionable nature of the intuition. Without such explicit validation, biased reasoners might not be willing to give up their intuitive heuristic answer [4,28]. Nevertheless, no matter how the precise nature of the inhibition failure is filled in, the key distinctive claim of this account is that both biased and unbiased thinkers can easily detect that the heuristic response is questionable on normative grounds [23,26,29–31]. Experimental evidence for this claim is summarized in Box 2.

The 'whens'

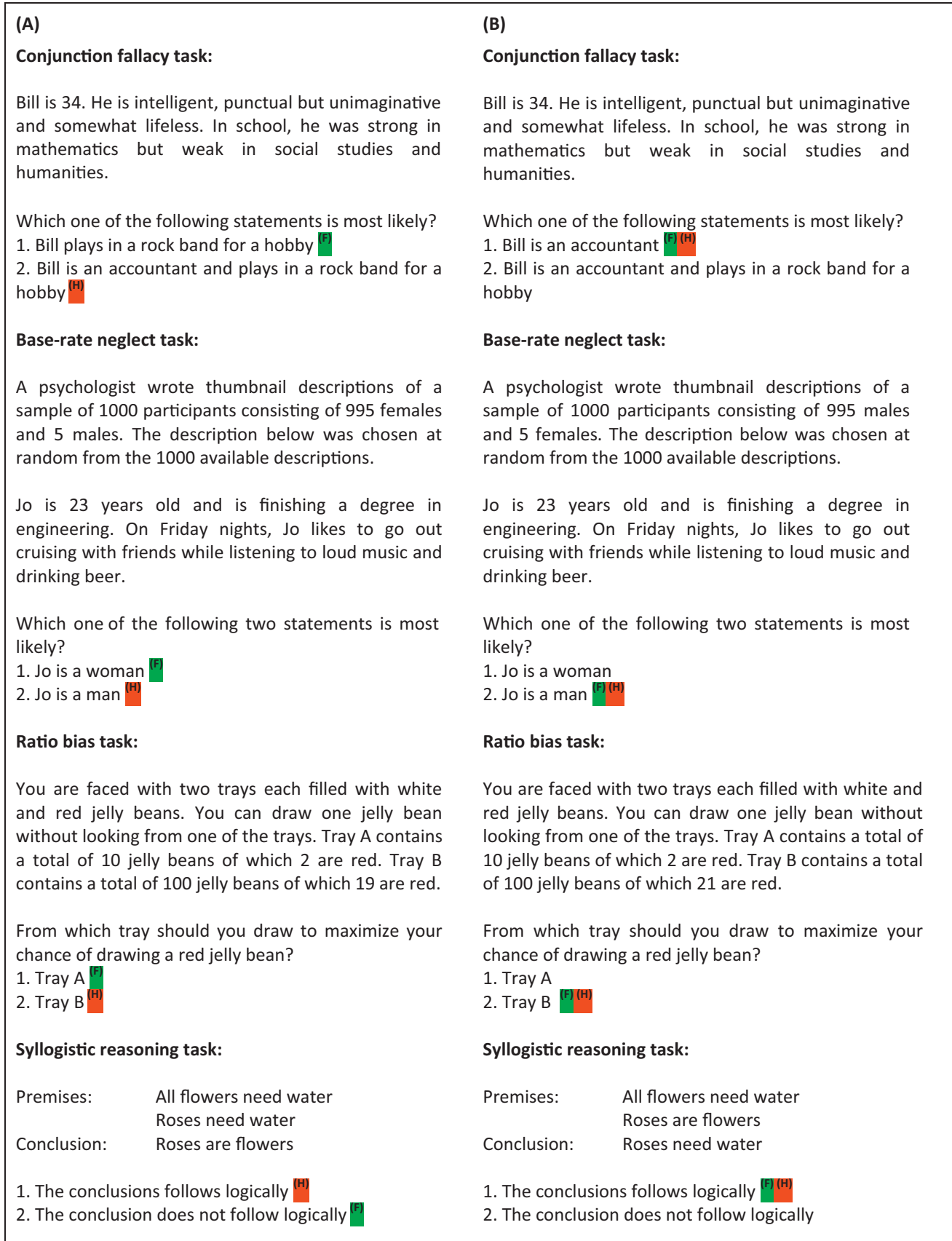
So far, we have organized thinking bias research in a partition that closely tracks the elementary components of reasoning: storage, monitoring, and inhibition. Bias (and the subsequent divergence between biased and unbiased reasoners) could result from a failure within each of these components. Although this focus on the cognitive locus of bias has unquestionably proven useful, we suspect that it has detracted attention from an equally important question, that of the timing of the divergence between biased and unbiased reasoners. Biased and unbiased reasoners clearly arrive at a different outcome by the end of the

Box 2. Evidence for successful conflict detection*Typical designs*

The basic question in conflict detection studies is whether reasoners are sensitive to the conflict between heuristic intuitions and formal principles, regardless of the response they eventually produce. These studies typically contrast classic problems known to encourage biased responses with newly constructed control versions (Figure 1). In the classic version of the problem, heuristic intuitions will cue a response that conflicts with the formal response. In the control version the conflict is removed and heuristic intuitions and formal principles cue the same response. The basic rationale for this design is that the two versions of the problem should be processed in the same manner according to the storage failure account, as well as the monitoring failure account – but not according to the inhibition failure account. If biased reasoners have not stored relevant formal principles or if they do not use them for monitoring conflicts, the two versions of the problem should be isomorphic and processed in the same manner.

Typical findings

Numerous processing measures suggest that reasoners (biased and unbiased alike) are remarkably sensitive to conflict. For example, it has been shown that even for biased reasoners, conflict problems, as compared to their control versions, result in increased response times [31,41,42], increased autonomic activation [43], increased activation of brain regions supposed to mediate conflict detection [44], increased inspection of logically critical problem parts [18,45], and decreased accessibility of semantic knowledge related to the intuitive heuristic response [46]. In addition, biased reasoners also show decreased response confidence after solving the classic conflict version of a problem [47]. All these results suggest that biased reasoners detect conflict just as unbiased reasoners and can literally sense that their heuristic response is questionable on formal grounds. The fact that even biased reasoners show these conflict-related processing effects has been taken as evidence that bias does not result from a detection failure per se [23,31,41,48] (but see also [49,50]).



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Figure 1. Illustrations of bias tasks. Popular tasks that have been used to demonstrate the biased nature of people’s thinking. The left panel (A) shows the classic versions and the right panel (B) newly constructed control versions used in conflict detection studies. The classic versions cue a heuristic response that conflicts with the correct formal response (Box 1). In the control versions, small content transformations guarantee that the cued heuristic response is consistent with the formal response. The ■ sign denotes the correct formal response and the ■ sign denotes the cued heuristic response in each of the tasks.

reasoning process. But when in the process does this individual variance arise? Do biased and unbiased reasoners take a different cognitive route from the onset or do they initially walk the same cognitive path and head in different directions during the later stages of the reasoning process?

Early and late divergence

As Figure 1 illustrates (bottom panel), the storage failure, monitoring failure, and inhibition failure accounts correspond to different views about the point in time at which biased and unbiased reasoners will diverge. Indeed, the three components (storage, monitoring, inhibition) can be ordered on a timeline from early to late in the reasoning process. Hence, different perspectives on which component is the major source of bias are committed to different views about the timing of individual differences in thinking biases. When looking at the individual differences debate through this lens, it becomes clear that the storage failure account, the monitoring failure account, and some versions of the alternative norms account (Box 1) share an underlying assumption. Namely, they all assume an early divergence between biased and unbiased reasoners. Whether biased reasoners have not stored some relevant formal knowledge or they do not use it to monitor for conflict, the bottom line is that they do not take formal principles into account and are forced to follow the intuitive heuristic route from the outset.

By contrast, the inhibition failure view entails a late divergence point. According to this view, biased and unbiased reasoners alike use their stored formal knowledge for monitoring conflicts with heuristic intuitions, they all achieve this conflict detection, but diverge in the latest stage of the reasoning process, that of inhibiting their heuristic response. The emerging evidence about reasoners' conflict sensitivity (Box 2) would appear to speak in favor of a late divergence. Although these data do not settle the question of why biased and unbiased reasoners ultimately fail to inhibit and diverge after successful detection, they do argue against an early conceptualization of the divergence.

Insights from the 'whens'

The 'whys' and 'whens' of individual differences in thinking biases are two closely related questions (to the extent that any evidence that informs one question is likely to also inform the other). As intricate as these two questions might be, their simultaneous consideration brings a fresh outlook on individual differences in thinking biases.

First, looking at the 'whens' can put in perspective how deep the individual differences are, as compared to what the 'whys' would suggest. Research on the cognitive locus of bias might give the impression that there are profound differences between biased and unbiased reasoners, an impression that can be corrected by considering the timing of the divergence between the two groups. The storage and monitoring failure accounts, for example, can suggest a picture of biased and unbiased reasoners as drivers who take completely separate routes to arrive at their heuristic or formal destination. The emerging evidence for a late divergence, however, would suggest that individual differences

are less profound than what this picture evokes: biased and non-biased reasoners can be better thought of as drivers on the same highway, who take different exits only at the very end of their journey. Note that what we call 'profoundly' different reasoners are reasoners who share little in terms of cognitive processing. This does not entail that a late arising individual difference is easier to overcome (e.g., by educational intervention or training) than an early arising one.

Second, an emphasis on the 'whens' (rather than the 'whys') can help to refine models of individual differences by directing attention to intra-individual differences in thinking biases. Indeed, a single individual may appear biased in one occasion, but unbiased in another. That is, as we noted in the introduction, the locus of individual differences need not be fixed and might vary between tasks or context [12]. A focus on the 'whens' naturally accommodates this intra-individual variation. Just as biased and unbiased reasoners walk the same cognitive path up until a certain point where they diverge, a given individual might

Box 3. Outstanding questions

- *The 'whys' again*

It should be clear that our argument to take the timing of individual bias differences into account does not downplay the importance of the 'why' question. The evidence for late divergence points posited by the inhibition failure account is open to different interpretations. It will be important that future work clarifies the precise nature of the late arising inhibition failure.

- *Quantifying the timeline*

At this point, our claims with respect to the timing of individual divergence are purely qualitative. For example, inhibition failure is supposed to occur later in the reasoning process than storage or monitoring failure: it will be useful to quantify this timeline more precisely in future studies. One possibility would be to use electroencephalography (EEG) and measure when precisely biased and unbiased reasoners' processing of conflict and no-conflict problems starts to differ (e.g., see A. Banks and C. Hope, unpublished).

- *Subtyping the reasoners*

Our overview of the key positions focused on the typical nature of a biased response, as given by the majority of biased reasoners. As we noted, this does not entail that different reasoners cannot be biased for different reasons. For example, proponents of the monitoring failure account would not contest that some biased reasoners might detect conflict [1]. And conversely, proponents of the inhibition failure account would not deny that sometimes storage failure might be the correct explanation for bias [23]. It will be interesting to directly look for and characterize smaller subgroups which might diverge at different time points. Therefore, future conflict detection or timing studies will need to move from a group-level (biased vs unbiased response) to an individual-level analysis.

- *Individual differences in individual differences*

More broadly, just as different sub-groups of reasoners might be biased for different reasons, one and the same reasoner can be biased for different reasons on different occasions. In general, the locus of individual differences can be contingent on specific task, context, person, or developmental factors [12,51]. For example, salient features in some tasks (e.g., extreme ratios in base-rate problems; see Figure 1 in Box 2) may facilitate conflict detection [49]. Emerging developmental work also suggests that monitoring failures might be more likely early on in development [52]. Likewise, one can imagine that for individuals who lack any formal education (e.g., infants or people in rural tribes) storage failures can become more dominant (but see also [53,54]). Identifying and mapping such contextual variability in the locus and timing of individual differences will be an important area for future research.

walk her usual path for a longer or a shorter distance, depending on the occasion. The point at which she diverges from this path, on any given occasion, will determine the nature of the bias, or lack thereof, that she will display (see **Box 3** for a related point).

Third, thinking in terms of ‘whens’ can shine a new light on the alternative norms account introduced in **Box 1**. As we saw, this account is compatible with various ‘whys’, that is, various cognitive loci for thinking biases. Data on the ‘whens’ can thus impose further theoretical constraints on this account and discriminate between its variants. For example, data in favor of a late divergence, such as the fact that biased reasoners detect a conflict between their response and classic norms, would argue directly against the idea that they consider these norms as irrelevant [32–34]. Even if different reasoners gave different weight to alternative norms, all reasoners would then seem to give some minimal, initial weight to classic formal norms. Only later in the reasoning process would they diverge from this cognitive path and take the route defined by an alternative norm.

Concluding remarks

Human reasoners often display thinking biases, but not all do to the same extent. Research on thinking biases has offered numerous explanations of these individual differences, which we have tentatively organized in two different but closely related ways. A focus on the ‘whys’ of thinking biases would distinguish between at least three main possible cognitive loci of bias (storage, monitoring, inhibition). As an alternative to the ‘whys’, a focus on the ‘whens’ would distinguish between different divergence points between the reasoning of biased and unbiased thinkers. The ‘why’ and the ‘when’ perspectives are closely related, but also complementary to some extent. A focus on the ‘whens’, and the evidence for a late divergence between biased and unbiased reasoners, can lead to several new insights on individual differences in thinking biases. Perhaps the most important of these insights is to attenuate a strong view of individual differences, in which biased and unbiased reasoning are conceived as fundamentally different processes. The late divergence view implies that individual differences are less profound, by suggesting that biased and unbiased reasoners walk the same cognitive path, until they diverge in the very end. In that sense, biased reasoners (*modulo* their diversity) are probably closer in cognitive functioning to unbiased reasoners than the literature might have traditionally suggested.

References

- Kahneman, D. (2011) *Thinking, Fast and Slow*, Farrar, Strauss, Giroux
- Tversky, A. and Kahneman, D. (1974) Judgment under uncertainty: heuristics and biases. *Science* 185, 1124–1131
- Evans, J. (2008) Dual-processing accounts of reasoning, judgment, and social cognition. *Annu. Rev. Psychol.* 59, 255–278
- Stanovich, K.E. (2010) *Rationality and the Reflective Mind*, Oxford University Press
- Stanovich, K.E. and West, R.F. (2000) Individual differences in reasoning: implications for the rationality debate? *Behav. Brain Sci.* 23, 645–726
- Stanovich, K.E. et al. (2008) The development of rational thought: a taxonomy of heuristics and biases. *Adv. Child Dev. Behav.* 36, 251–285
- Hilbert, M. (2012) Toward a synthesis of cognitive biases: how noisy information processing can bias human decision making. *Psychol. Bull.* 138, 211–237
- Reyna, V.F. and Brainerd, C.J. (2011) Dual processes in decision making and developmental neuroscience: a fuzzy-trace model. *Dev. Rev.* 31, 180–206
- Gigerenzer, G. and Brighton, H. (2009) Homo heuristicus: why biased minds make better inferences. *Top. Cogn. Sci.* 1, 107–143
- Reyna, V.F. et al. (2003) Memory, development, and rationality: an integrative theory of judgement and decision-making. In *Emerging Perspectives on Judgment and Decision Research* (Schneider, S. and Shanteau, J., eds), pp. 201–245, Cambridge University Press
- Evans, J. (2007) On the resolution of conflict in dual process theories of reasoning. *Think. Reas.* 13, 321–339
- Stanovich, K.E. and West, R.F. (2008) On the relative independence of thinking biases and cognitive ability. *J. Pers. Soc. Psychol.* 94, 672–695
- Inhelder, B. and Piaget, J. (1958) *The Growth of Logical Thinking*, Basic Books
- Wason, P.C. (1968) Reasoning about a rule. *Q. J. Exp. Psychol.* 20, 273–281
- Stanovich, K.E. (2009) Distinguishing the reflective, algorithmic, and autonomous minds: Is it time for a tri-process theory? In *In Two Minds: Dual Processes and Beyond* (Evans, J.B.S.T. and Frankish, K., eds), pp. 55–88, Oxford University Press
- Kahneman, D. and Frederick, S. (2002) Representativeness revisited: attribute substitution in intuitive judgement. In *Heuristics and Biases: The Psychology of Intuitive Judgement* (Gilovich, T. et al., eds), pp. 49–81, Cambridge University Press
- Evans, J.B.S.T. (2010) Intuition and reasoning: a dual process perspective. *Psychol. Inq.* 21, 313–326
- De Neys, W. and Glumicic, T. (2008) Conflict monitoring in dual process theories of reasoning. *Cognition* 106, 1248–1299
- Wason, P.C. and Evans, J. (1975) Dual processes in reasoning. *Cognition* 3, 141–154
- Alter, A.L. et al. (2007) Overcoming intuition: metacognitive difficulty activates analytic reasoning. *J. Exp. Psychol. Gen.* 136, 569–576
- Thompson, V.A. and Morsanyi, K. (2012) Analytic thinking: do you feel like it? *Mind Soc.* 11, 93–105
- Thompson, V.A. (2009) Dual process theories: a metacognitive perspective. In *In Two Minds: Dual Processes and Beyond* (Evans, J.B.S.T. and Frankish, K., eds), pp. 171–195, Oxford University Press
- De Neys, W. (2012) Bias and conflict: a case for logical intuitions. *Perspect. Psychol. Sci.* 7, 28–38
- Thompson, V.A. et al. (2011) Intuition, reason, and metacognition. *Cogn. Psychol.* 63, 107–140
- Oppenheimer, D.M. (2008) The secret life of fluency. *Trends Cogn. Sci.* 12, 237–241
- Epstein, S. (2010) Demystifying intuition: what it is, what it does, and how it does it. *Psychol. Inq.* 21, 295–312
- Houde, O. and Tzourio-Mazoyer, N. (2003) Neural foundations of logical and mathematical cognition. *Nat. Rev. Neurosci.* 4, 507–514
- Evans, J.B.S.T. (2009) How many dual process theories do we need: one, two or many? In *In Two Minds: Dual Processes and Beyond* (Evans, J.B.S.T. and Frankish, K., eds), pp. 33–54, Oxford University Press
- Handley, S.J. et al. (2011) Logic, beliefs, and instruction: a test of the default interventionist account of belief bias. *J. Exp. Psychol. Learn. Mem. Cogn.* 37, 28–43
- Houde, O. (2007) First insights on ‘neuropsychology of reasoning’. *Think. Reas.* 13, 81–89
- Bonner, C. and Newell, B.R. (2010) In conflict with ourselves? An investigation of heuristic and analytic processes in decision making. *Mem. Cogn.* 38, 186–196
- Oaksford, M. and Chater, N. (2007) *Baysian Rationality: The Probabilistic Approach to Human Reasoning*, Oxford University Press
- Mercier, H. and Sperber, D. (2011) Why do humans reason? Arguments for an argumentative theory. *Behav. Brain Sci.* 34, 57–111
- Gigerenzer, G. (1996) On narrow norms and vague heuristics: a reply to Kahneman and Tversky (1996). *Psychol. Rev.* 103, 592–596
- Pfeifer, N. and Kleiter, G.D. (2009) Framing human inference by coherence based probability logic. *J. Appl. Logic* 7, 206–217
- Stenning, K. and van Lambalgen, M. (2008) *Human Reasoning and Cognitive Science*, MIT Press

- 37 Stenning, K. and Van Lambalgen, M. (2010) The logical response to a noisy world. In *Cognition and Conditionals: Probability and Logic in Human Thinking* (Oaksford, M. and Chater, N., eds), pp. 85–102, Oxford University Press
- 38 Benferhat, S. *et al.* (2005) An overview of possibilistic handling of default reasoning, with experimental studies. *Synthese* 146, 53–70
- 39 Hertwig, R. *et al.* (2008) The conjunction fallacy and the many meanings of and. *Cognition* 108, 740–753
- 40 Kruglanski, A.W. and Gigerenzer, G. (2011) Intuitive and deliberate judgments are based on common principles. *Psychol. Rev.* 118, 97–109
- 41 Villejoubert, G. (2009) Are representativeness judgments automatic and rapid? The effect of time pressure on the conjunction fallacy. In *Proceedings of the Annual Meeting of the Cognitive Science Society* 30 (Taatgen, N. *et al.*, eds), pp. 2980–2985, Cognitive Science Society
- 42 Stupple, E.J.N. and Ball, L.J. (2008) Belief-logic conflict resolution in syllogistic reasoning: Inspection-time evidence for a parallel-process model. *Think. Reas.* 14, 168–181
- 43 De Neys, W. *et al.* (2010) Feeling we're biased: autonomic arousal and reasoning conflict. *Cogn. Affect. Behav. Neurosci.* 10, 208–216
- 44 De Neys, W. *et al.* (2008) Smarter than we think: when our brains detect that we are biased. *Psychol. Sci.* 19, 483–489
- 45 Ball, L.J. *et al.* (2006) Effects of belief and logic on syllogistic reasoning – eye-movement evidence for selective processing models. *Exp. Psychol.* 53, 77–86
- 46 De Neys, W. and Franssens, S. (2009) Belief inhibition during thinking: not always winning but at least taking part. *Cognition* 113, 45–61
- 47 De Neys, W. *et al.* (2011) Biased but in doubt: conflict and decision confidence. *PLoS ONE* 6, e15954
- 48 Morsanyi, K. and Handley, S.J. (2012) Logic feels so good – I like it! Evidence for intuitive detection of logic in syllogistic reasoning. *J. Exp. Psychol. Learn. Mem. Cogn.* 38, 596–616
- 49 Pennycook, G. *et al.* (2012) Are we good at detecting conflict during reasoning? *Cognition* 124, 101–106
- 50 Klauer, K.C. and Singmann, H. (2012) Does logic feel good? Testing for intuitive detection of logic in syllogistic reasoning. *J. Exp. Psychol. Learn. Mem. Cogn.* <http://dx.doi.org/10.1037/a0030530>
- 51 Stanovich, K.E. *et al.* (2011) The complexity of developmental predictions from dual process models. *Dev. Rev.* 31, 103–118
- 52 De Neys, W. and Feremans, V. (2012) Development of heuristic bias detection in elementary school. *Dev. Psychol.* <http://dx.doi.org/10.1037/a0028320>
- 53 Teglas, E. *et al.* (2011) Pure reasoning in 12-month-old infants as probabilistic inference. *Science* 332, 1054–1059
- 54 Xu, F. and Kushnir, T. (2013) Infants are rational constructivist learners. *Curr. Dir. Psychol. Sci.* 22, 28–32