Who detects and why: How individual differences in cognitive characteristics underpin different types of responses on reasoning tasks?

Nikola Erceg[1*], Zvonimir Galić[1], Andreja Bubić[2], Dino Jelić[1]

[1] Faculty of Humanities and Social Sciences, University of Zagreb, Croatia

[2] Faculty of Humanities and Social Sciences, University of Split, Croatia

* Corresponding author

This manuscript is a preprint and has not been peer-reviewed.

This work is a part of the project “Implicit personality, decision making and organizational leadership” funded by the Croatian science foundation (Grant no. 9354)

The data is available here: https://osf.io/se2uk/

Abstract

People can solve reasoning tasks in different ways depending on how much conflict they detected and whether they were accurate or not. Hybrid dual-process model presumes that these different types of responses correspond to different strengths of logical intuitions, with correct responses given with little conflict detection indicating very strong, and incorrect responses given with little conflict detection very weak logical intuitions. Across two studies, we observed that individual differences in abilities, skills and dispositions underpinned these different response types, with correct non-detection trials being related to highest, and incorrect non-detection trials to lowest scores on these traits, both for cognitive reflection and belief-bias tasks. In sum, it seems that every individual difference variable that we measured was important for development of strong logical intuitions, with numeracy and need for cognition being especially important for intuitive correct responding on cognitive reflection tasks. In line with hybrid dual-process model, we argue that abilities and dispositions serve primarily for developing mindware and strong intuitions, and not for detecting conflict, which has repercussions for validity of these tasks as measures of reflection/analytical thinking.

Keywords: Cognitive reflection; Belief bias; Conflict detection; Individual differences; Logical intuitions.

Who detects and why?
Individual differences in abilities, knowledge and thinking dispositions among different types of problem solvers and their implications for the validity of reasoning tasks

1. Introduction

One of the most famous problems in the decision-making literature is the “bat and a ball” problem from the cognitive reflection test (CRT; Frederick, 2005). The problem goes as follows: „A bat and a ball cost $1.10 in total. The bat costs $1 more than the ball. How much does the ball cost?“ Similarly as other problems from this test, this one automatically triggers relatively strong initial response (i.e., 10 cents). However, after a more careful reflection, it becomes clear that the right response is in fact 5 cents. The test became widely popular because it elegantly illustrates main points of the dual-process theories of reasoning.

Dual-process theories characterize human thinking and reasoning as an interplay of fast, automatic, autonomous and non-conscious System 1 and slower, rule-based, effortful deliberate System 2 (De Neys, 2012; 2015; Evans & Stanovich, 2013; Kahneman, 2011). A more recent expansion of the dual-process model is the tripartite theory (Stanovich, 2009; Stanovich, West & Toplak, 2016) that further differentiates between two aspects of System 2 processing, the reflective and the algorithmic mind. It is this interplay between the two systems that is elegantly captured by the CRT items. In order to overcome the initial wrong response generated by the fast and automatic System 1 (10 cents) and arrive at the correct one (5 cents), one has to reflect on the answer and recognize the need to engage in a more deliberate processing (the reflective mind), but also to possess adequate computational power, knowledge and abilities to calculate the right answer (algorithmic mind).

There are two basic models of the dual-process theories. According to the first, default-interventionist model, the two systems operate serially. Automatic and fast System 1 processes are activated first and they produce an intuitive, heuristic response (Evans, 2006; Kahneman & Frederick, 2005). In order to arrive at the correct conclusion, System 2 must “intervene” and change this default, heuristic response. Therefore, when one gives a heuristic response to the problems such as the CRT problem above, it is because one failed to engage in effortful and deliberate System 2 processing. That can be either because one did not recognize the need to engage in more deliberate processing (lack of the reflective mind) or because (s)he simply lacked the ability to calculate the right response (lack of the algorithmic mind). When the correct response is given it has to be because the System 2 intervened and inhibited the invalid, heuristic response (Travers, Rolison & Feeney, 2016). According to the second, parallel activation model, the two systems do not act serially one after the other but are both active at the same time, simultaneously computing a problem solution from the start and competing for a control of response and behavior (Handley & Trippas, 2015; Sloman, 1996; 2014; Trippas & Handley, 2018). Both of these models face a problem when trying to explain how and when a reasoner detects that the output from the intuitive System 1 is wrong and in conflict with the correct response. On the one hand, the default-interventionist model has a hard time explaining how a reasoner can ever detect the conflict if the System 2 is not already engaged from the start. On the other hand, the parallel activation model unrealistically expects that the harder and more cognitively demanding System 2 processing will be engaged from the very start of a reasoning process (De Neys, 2015).

A new, hybrid model of logical intuitions was recently proposed (De Neys, 2012, 2014, 2015; Pennycook, Fugelsang & Koehler, 2015). The logical intuitions model represents a modification of traditional dual process theories as it takes into account evidence indicating that people are generally implicitly aware of the conflict between the heuristic and normative response, even in the cases when they select the incorrect response. The typical experimental paradigm for studying the conflict detection contrasts the original problem that cues the wrong heuristic response (such as the bat-and-ball problem) with the similar no-conflict problem where the heuristic response is aligned with the normative response and where the participants are not being lured into giving wrong response. For example, a no-conflict version of the bat-and-ball problem would be: “A bat and a ball cost $1.10 in total. The bat costs $1. How much does the ball cost?” (De Neys, Rossi, & Houdé, 2013). Unlike the original version of the problem, this version does not cue the wrong response and should be much easier to solve for participants. After answering both the conflict and no-conflict question, participants are asked to indicate the confidence in their answers. Naturally, since the no-conflict version of the problem is trivially easy and mostly solved correctly, participants are quite confident in their responses. The logic behind asking for confidence ratings is that, if people do not notice that they are being lured into a wrong response on the original conflict task, then they should perceive the two problems to be essentially the same, i.e. trivial. Therefore, they should be similarly confident in their responses.

However, people seem to be less confident in their responses on the original conflict task than on the parallel no-conflict task also in the cases when they end up giving the wrong heuristic response (De Neys, Cromheeke, & Osman, 2011; De Neys et al., 2013). As this drop of confidence does not come from deliberate and careful thinking, the authors have proposed that the intuitive System 1 is also sensitive to logical principles and mathematical rules and that, at least under certain conditions, it is capable of producing both the incorrect heuristic and correct normative response. These System 1 produced responses that are in accordance with logical and mathematical rules are called logical intuitions (but see Ghasemi, Handley, Howarth, Newman & Thompson, 2021). These findings are the basis of the previously described hybrid dual-process model. Given that intuitions are activated at some level, people detect the conflict and are aware that something is happening even if not quite sure what. In the case when the heuristic and normative responses are in conflict, this conflict creates a sense of arousal that signals people to doubt their heuristic response and lower the confidence (De Neys, 2015) which sometimes leads to better accuracy on reasoning problems (e.g. Šrol & De Neys, 2021).

In addition to the decreased confidence ratings (Bago & De Neys, 2017; De Neys, et al., 2011, 2013; Frey, Johnson, & De Neys, 2018; Mevel et al., 2015; Stupple, Ball, & Ellis, 2013), other indicators of conflict detection on reasoning tasks have been studied. For example, Stupple, Pitchford, Ball, Hunt and Steel (2017) assert that conflict detection should also be observable from the response times (RT) on such tasks. If people detect the conflict between the heuristically wrong and normative right answer, they should be more careful when solving the problem resulting in longer RTs compared to those that do not detect the conflict, and this increase in time should be related to greater accuracy on the task. In this regard, studies are equivocal as some found positive correlation between response accuracy and RTs (although the effect sizes are quite modest, e.g. $r = .18$ in Stupple et al., 2017) while others failed to find such correlation (e.g. Damnjanović, Novković, Pavlović, Ilić and Pantelić, 2019). However, it must be noted that response time can only be noisy and imperfect proxy for conflict detection as prolonged time can, for example, just mean that a person has a preference towards slower and more careful approach when solving problems (Bago & De Neys, 2017). To control for this overall preference, similarly as with the confidence ratings, it is possible to compare the RTs between conflict and no-conflict tasks. These studies generally show that people spend more time solving a conflict task in comparison with its no-conflict counterpart (e.g. De Neys & Glumicic, 2008; Frey et al., 2018; Johnson, Tubau, & De Neys, 2016), although this prolonged time failed to result in higher accuracy in several recent studies (Swan, Calvillo and Revlin, 2018; Šrol & De Neys, 2021; Teovanović, 2019). Taken together, the confidence and response time differences between the conflict and no-conflict task, as well as simple response time that one takes to complete the reasoning task could be taken as indicators of conflict detection. As Šrol and De Neys (2021) point out, any single detection indicator is imperfect and could therefore point to different conclusions, so it is useful to use several indicators simultaneously in a study.

Considering that many conflict detection studies seem to show that conflict detection is ubiquitous and present even among the people that fail to solve the reasoning conflict tasks correctly, some authors speculate that logical intuitions are universal. For example, De Neys (2015) asserted that the “lack of individual differences in conflict detection efficiency further suggests that the necessary normative knowledge activation is indeed effortless” (pp. 31). However, studies investigating individual differences in conflict detection suggest that conflict detection, as well as logical intuitions, might not be that universal after all. For example, in Mevel et al. (2015) study, only 56% of biased respondents showed a confidence decrease on the ratio bias reasoning task (e.g. assessing a probability of drawing a red marble from a tray of red and white marbles based on the relative proportion and not total number of red marbles), indicating that only about half of the participants that failed to correctly solve the problem actually detected the problem. Similarly, Frey et al. (2018) reported that 66% of biased respondents showed signs of conflict detection on the base-rate problem, 57% on the conjunction problem and only 38% on the bat-and-ball problem. Therefore, it seems that although a relatively large proportion of participants in fact detects the conflict, there is also a substantial proportion of those “happy fools” (De Neys et al., 2013) that do not detect it and proceed with giving the wrong response without ever doubting it.

Furthermore, there are also people who seem to be able to instantly give the right response on the reasoning tasks with showing very little signs of conflict detection. The two-response paradigm is especially suitable for studying this. In this paradigm, the participants give their responses to the same task two times: the first response is given under the strict deadline to ensure that it is in fact a product of an intuitive System 1 processing, while the other is given without constraints, and respondents can change their original response (Thompson & Johnson, 2014; Thompson, Turner & Pennycook, 2011). Using this paradigm, Bago and De Neys (2017) showed that approximately 30% to 40% of participants intuitively gave the correct responses on base-rate problems and belief-bias syllogisms, in comparison to only 6% to 10% of those that gave intuitively incorrect response, but corrected it later through deliberation, as default-interventionist dual-process view would predict. The results were similar for CRT problems too – although majority of participants responds incorrectly to these problems, when a correct response is given, in around two-thirds of the cases it is generated intuitively, from the start, and only rarely through additional deliberation (Bago & De Neys, 2019). Similarly, using the protocol analysis, Szaszi, Szollosi, Palfi and Aczel (2017) demonstrated that majority of participants who correctly solved CRT items (77%), immediately started their response with correct answer or with a line of reasoning leading to a correct answer. Only the minority (23%) started their response with an incorrect answer and then, through deliberative thinking, actually concluded that it was wrong and came up with the right answer. These results strongly indicate that correct responses to reasoning problems in majority of cases are generated intuitively. This represents a big problem for the classical dual-process views that posits that the correct responses should be reached through the activation of slow and deliberate System 2 processes. So, how can these findings be explained and reconciled with the dual-process position?

Recently Bago and De Neys (2017, 2019, 2020) extended the hybrid, logical intuition view with a notion of differential intuition strength. They built this model on Pennycook et al. (2015) three-stage model of analytic engagement. In short, this model posits that in the first stage, the autonomous Type 1 processes generate several intuitive responses and that some of those intuitive responses come to mind faster and more fluently than others. If one response substantially dominates the others in terms of this fluency, than no conflict between the responses will be detected and this intuitive response would be the final one. If, however, no initial response significantly dominated the others in terms of ease of generation, the person might detect that two or more of the initial responses are in conflict one with another. In this case of conflict detection, according to Pennycook et al. (2015), there are two possibilities. First, a person can focus on justifying and elaborating the first intuitive response without giving a serious thought to the competing response(s), presumably because the first one came to mind somewhat easier than the others. The authors call this process the rationalization. Alternatively, after detecting the conflict, a person can engage in what is typically seen as analytical thinking, conclude that the initial response is not the best one after all, and opt for another response that seems better after more careful deliberation.

Although the initial Pennycook et al. (2015) model does not explicitly state that the dominant intuitive response will be an incorrect one, it nevertheless seems to imply it. For example, they say that the process of rationalization “leads to a response in line with what would typically be considered bias (i.e., one’s strongest intuition, which will often be personally relevant), but that has been bolstered by analytic reasoning (an ‘‘effortful’’ belief-based response)” (p. 40). Thus, it seems that, at least implicitly, the model presumes that the dominant intuition will in most cases be incorrect.

However, as it is clear for the two-response studies described before, this does not have to be the case and in many cases - it is not. Bago and De Neys (2017, 2019) model explicitly accounts for this by presuming that the initial and final responses will depend on the absolute and relative strengths of different intuitive responses that are generated, of which one will typically be the normatively correct response, the product of logical intuition. Specifically, according to their differential intuition strength view, the initial, intuitive responses in a two-response paradigm will depend on the absolute strength of the intuition. If the logical intuition is stronger than the incorrect one, then the initial response will be correct, otherwise it will be incorrect. The subsequent conflict detection will depend on the relative strengths of competing intuitions. If logical and incorrect intuitions are roughly similar in strength, i.e. no response is particularly more salient or fluent, the person will then probably detect the conflict between those responses. The more similar the strength of intuitions, the greater the probability of conflict detection. Conversely, the greater the difference in the strength of intuitions, the lower the probability of conflict detection. These differences in the intuition strengths can elegantly account for the recent findings that contradicted the traditional dual-process views. For example, intuitive correct response when respondents show very little signs of conflict detection is probably due to logical intuition being substantially stronger than the incorrect one, while incorrect responses even after a period of deliberation point to the opposite (i.e., logical intuition being substantially weaker than the incorrect one). What was previously thought to be a predominant way of solving these reasoning tasks, by detecting and overriding a conflict through a deliberation, would only be instances where the intuitions are similar in strength.

WHO DETECTS AND WHY?

The question is what influences the strengths of different types of intuitions. Recent studies show that one of the significant bottom-up influences are task characteristics. For example, it has been shown that the manipulation of base-rate extremity in base-rate neglect tasks significantly affects the strength of the logical intuition. Specifically, when the base rates were moderate, significantly fewer participants responded intuitively correct than when the base rates were extreme, indicating that the logical intuition is significantly weaker with moderate base rates (Bago and De Neys, 2020). The abstractness of the task content also seems to impact the strength of intuitions. For example, when participants solved belief-bias syllogisms under strict time limit, they were more successful when the content of the tasks was concrete and familiar than when it was abstract or non-sensical, indicating that the type of content also influences the strength of logical intuitions (Markovits, de Chantal, Brisson, & Gagnon-St-Pierre, 2019; Markovits et al., 2021). However, what is more relevant for our study than these bottom-up influences are top-down influences in terms of person's characteristics. In other words, what kind of abilities, dispositions, skills, or knowledge affects the strength of one's logical intuitions?

In his recent work, Stanovich (2018) proposed that the mindware, i.e. specific knowledge and skills one gains through experience, is a key variable that affects the strength of logical intuitions for a given task. Recently, Purcell, Wastell and Sweller (2020) nicely elaborated on how this idea of differential mindware instantiation aligns with a hybrid dual-process model. Basically, as person's mindware (i.e. domain specific experiences and skills) becomes more advanced, he/she relies less on working memory and Type 2 processes. In the beginning, with no experience, a person does not possess any kind of relevant mindware, thus having no or very weak logical intuitions related to the problem at hand. With such an underdeveloped mindware, the potential for conflict detection is very weak as there is no logical intuition strong enough to conflict with the incorrect one. Thus, the intuitive incorrect response given with little thought is the most probable response in the first phase. However, as a person progresses with learning and practicing, his/her mindware becomes more developed, increasing the strength of logical intuitions. When a mindware becomes learned to a sufficient degree, a logical intuition can become as strong as any other. It is at this stage of mindware instantiation that the conflict detection and override become possible through engagement of Type 2 processes. If the conflict is strong enough, a person can engage in a deliberate, analytical thinking and, drawing from the acquired mindware, reject an incorrect intuitive response in favor of the correct one. Further down the road, with sufficient experience and practice, a mindware can become overlearned to a degree that the correct response becomes automatic. In other words, with such developed mindware (rich knowledge and experience related to a specific task at hand), logical intuitions can become so strong and come to mind so easily as to completely dominate over the incorrect one. When this happens, a person can give a correct response instantly with little to no conflict detected.

In sum, it can be said that there are three key phases in regard to the development and instantiation of mindware and corresponding reliance on different types of thinking. In the first phase, with underdeveloped mindware, a person employs a Type 1 processing, resulting in generally incorrect responses with little conflict detected. In the second phase, a person employs Type 2 thinking, drawing on the acquired mindware and increasing the chance of correct responses. Finally, in the third phase, a person again employs a Type 1 thinking, only this time giving mostly correct responses with little conflict detection due to overlearned and highly developed and automatized mindware (Stanovich 2018; Purcell at al., 2020). Purcell et al. (2020) have only partially confirmed these hypotheses, namely in the case when mindware quality was operationalized by real-life mathematical expertise and experience (undergraduate psychology students as low-experience group, undergraduate science and engineering students as intermediate experience group and postgraduate mathematical students as high experience group), but not when it was experimentally manipulated. In the former case, the intermediate experience group hypothesized to rely on Type 2 processes when solving CRT tasks indeed scored significantly lower when their deliberative abilities were constrained compared to unconstrained situation. This indicates that this group was indeed able to reach correct response if allowed enough time to do so, i.e. they were able to come up with correct response through Type 2 processes. Conversely, low and high experience group did not show diminished performance in constrained vs. unconstrained condition. Low experience group was similarly bad in both conditions, indicating that they accepted their incorrect initial response with little questioning of the response, presumably due to underdeveloped mindware that would allow them to detect the conflict between the correct and incorrect intuition. High experience group responded in a similar fashion – by responding intuitively – only their intuition was correct from the start, indicating that their overlearned mindware could have produced very strong correct, logical intuition, much stronger that the incorrect one.

Several recent studies confirmed the quintessential role of mindware in successful responding on reasoning tasks. The most direct test was reported by Šrol ad De Neys (2021) who showed that mindware instantiation was single best predictor of both conflict detection efficiency and overall accuracy on reasoning tasks, even after accounting for the effects of several important individual differences measures (cognitive ability, numeracy and need for cognition). Apart from this study, at least two recent studies showed how development of mindware boosts intuitive correct responding. Specifically, Boissin, Caparos, Raoelison and De Neys (2021) demonstrated how training participants on CRT-like tasks not only significantly increased their final responses in the two-response paradigm, but also their initial, intuitive responses, and these effects were sustained over a two-month period. The authors speculated that the short training boosted participants' mindware by reminding them how to use the knowledge that they already possessed, i.e. by making that knowledge and its usage more available in participants' minds. Finally, an elegant test of the "automatized mindware" idea was conducted by Raoelison, Boissin, Borst and De Neys (2021). They demonstrated how the development and automatization of the relevant mindware in children between 7th and 12th grade dramatically impacted the way they responded to reasoning problems (base-rate neglect and belief-bias syllogisms). Older children were not only more likely to deliberately correct an erroneous initial response, but also to generate a correct response from the start, confirming the crucial role of mindware instantiation in developing strong logical intuitions.

The question is how do the individual differences in cognitive abilities and thinking dispositions fit with this view of the crucial role of mindware. The hybrid dual-process theory throws an interesting and new perspective on the role of cognitive abilities and dispositions in the success on reasoning tasks. Currently, the dominant view in the literature is the "smart deliberator" view that assumes that people with higher cognitive abilities are better at reasoning tasks because they are better at correcting erroneous intuitions (cf. Raoelison, Thompson, & De Neys, 2020). Similar can be said for thinking dispositions such as disposition to engage in analytical thinking that has been dubbed to influence the motivation to engage in deliberative correction of intuitive incorrect responses. This view, for example, follows from the tripartite theory of Stanovich and colleagues (e.g. Stanovich, 2009; Stanovich et al., 2016) which posits that cognitive abilities and thinking dispositions are jointly responsible for recognizing, overturning and correcting the intuitive incorrect responses.

However, the hybrid dual-process model suggests that abilities and dispositions could affect the performance on tasks not because they help one to overcome intuitive response but because they are crucial for developing strong logical intuitions. As Evans (2019) put it, high ability people are better at solving different reasoning tasks because they are more practiced in reasoning and have thus automated some of the skills required for successful responding to certain type of tasks, such as processing numerical information. In other words, high abilities and dispositions towards analytical thinking could predispose some people to search for situations in which they can gain specific knowledge and skills (i.e., some people can show preference for complex problems that require hard thinking, such as difficult mathematical or logical problems) and also allow them to learn more and more quickly from such situations. With practice, these people will develop relevant mindware and automatize it to the degree that it will allow them to respond correctly on reasoning tasks by following their logical intuitions. From this view, it would follow that, for example, people who in two-response studies respond correctly from the start (what is usually coded as “11” responses) should have higher cognitive abilities and disposition to engage in analytical thinking than those who would respond correctly through deliberation (typically coded as “01” responses). Conversely, “smart deliberator” view would predict no differences between those responses, or even “01” responders scoring higher on cognitive ability and thinking disposition measures than “11” responders.

There were only few studies so far that aimed at investigating whether cognitive abilities matter more for intuitive or deliberative responses, but the evidence seems to tip in favor of “smart intuitor” and not “smart deliberator” view. More specifically, Raoelison et al. (2020) showed that cognitive capacity was positively correlated with the probability of giving “01” responses (i.e. responding correctly through deliberate correction of erroneous intuition), but that correlation was significantly stronger for “11” responses, meaning that the cognitive capacity was more important for intuitively correct responding than for correct responding through corrective deliberation. Several other recent findings align with this conclusion. For example, Thompson, Pennycook, Trippas and Evans (2018) showed that for high-capacity reasoners, statistical intuitions were stronger than the incorrect, stereotypical one, interfering with the ability of high-capacity participants to produce stereotypical (in case of base-rate neglect tasks) or believable (in case of belief-bias syllogisms) responses. The opposite was true for low-capacity responders. This indicates again that cognitive ability matters more for developing strong logical intuitions and responding in line with them than for correcting incorrect initial responses. More recently, Schubert, Ferreira, Mata and Riemenschneider (2021) replicated these findings by again showing that high-ability participants performed worse when asked to assess the believability of a conclusion, rather than its logical validity. Again, strong logical intuition in high-ability responders seem to have interfered with the ability to produce a response based on erroneous intuition. However, this study has also investigated the role of thinking dispositions in addition to cognitive abilities. Unlike the cognitive abilities that were important foremost for intuitively correct responding, need for cognition as a disposition towards analytical thinking was related with successful conflict resolution, i.e. responding correctly through detecting the conflict and deliberately correcting incorrect intuitive responding. This is more in line with the "usual" view of the role of thinking dispositions as a motivation to engage in analytical thinking, and less in line with a view that thinking dispositions motivate people to expose to situations that facilitate development of relevant mindware and strong logical intuitions.

As it is clear from the introduction so far, hybrid model makes somewhat different assumptions about the role of cognitive abilities and thinking dispositions in success on reasoning tasks than "classical" default-interventionist or parallel dual-process model, and there are only few studies that have tested these assumptions. Our goal is to contribute to this body of evidence by broadening the range of individual difference variables and testing them by using two different methodological approaches. Specifically, the goal of the current study is to investigate the individual differences in cognitive abilities (intelligence and numeracy), thinking dispositions (actively open-minded thinking and need for cognition) and knowledge (high-school math knowledge) that underpin different ways of solving two reasoning tasks, cognitive reflection tasks and belief-bias syllogisms. Specifically, as it follows from Stanovich (2018) discussion and Purcell et al. (2020) elaboration, it is theoretically possible to differentiate between four different types of responding on reasoning tasks depending on the probability of conflict detection and accuracy. First, a person with underdeveloped mindware relevant for the task will probably give wrong responses with little signs of conflict detection as his/her logical intuitions will presumably be very weak. That should reflect in incorrect non-detection trials. Second, for those whose mindware became more developed, the strength of logical intuition will increase and they will probably start detecting the conflict between the intuitions. However, they can still end up giving an incorrect response which will reflect in incorrect detection trials. Third, for some reason (e.g. somewhat more developed mindware, higher abilities or dispositions to engage in analytical thinking), after detecting the conflict between the competing intuitions, a person can overturn his/her initial intuitive response in favor of the correct one (correct detection trials). Finally, a person can have highly developed and overlearned mindware so that his/her logical, correct intuition becomes so strong and overcomes an incorrect one to the degree that the person does not even experience a conflict between the intuitions, but intuitively responds in a correct way (correct non-detection trials).

In line with the literature review, we advanced following hypotheses.

a) When participants show little signs of conflict detection yet give the correct responses (correct non-detections), this is sign of strong logical intuitions that arise due to overlearned mindware. In this regard, we expect this type of responses to be associated with higher cognitive ability, numeracy, math skills and thinking dispositions towards analytical thinking than the other types of responses.

b) When participants show little signs of conflict detection and fail to respond correctly (incorrect non-detections), this implies very weak logical intuitions, probably due to the underdeveloped mindware. In this regard, we expect this type of responses to be associated with the lowest scores on cognitive ability, numeracy, math skills and thinking dispositions towards analytical thinking of all the four response types. By referring to this and previous trials as “non-detections”, we do not imply that those that respond in this way did not detect the conflict at all, but only that they show substantially weaker signs conflict-detection than the others (Bago & De Neys, 2017; 2019).

c) When participants detect the conflict and give correct responses (correct detections), they have more developed mindware compared to those that detect the conflict but give the incorrect response (incorrect detections). In this regard we expect the latter response type to be associated with lower scores on cognitive abilities, numeracy, math skills and thinking dispositions towards analytical thinking than the former response type.

We tried to answer our research questions by conducting two different studies. In the first one, we employed a single-response format and tried to capture conflict detection by combining three indicators, response time on reasoning tasks, response time differences and confidence differences between the tasks with and without lures. These differences in response times and confidences should indicate that a person detected the conflict between a logical and incorrect intuition that is evoked in tasks with lures, but not in those without lures. In the second study, we employed a two-response paradigm where participants first responded under strict time deadline and cognitive load, followed by responding without any time limit or cognitive strain. This approach allowed us to separate those that respond intuitively correctly from those that give correct responses through more pronounced conflict detection and corrective deliberation and those that do not manage to respond correctly even after deliberation. However, it must be noted that in the Study 2, due to time constraints, we did not use the tasks without lures. Therefore, we were not able to differentiate between incorrect responses on which the conflict was detected versus non-detected. Thus, in this case, we can only compare the three response types: correct non-detections, correct detections, and incorrect responses, regardless of the conflict detection.

2. Study 1

2.1. Methods

2.1.1. Participants

506 university students participated in our study (26.5% males). The mean age was 21.15 (min = 18, max = 31, SD = 2.13).

2.1.2. Instruments

CRT (Frederick, 2005) is an instrument that was designed with an aim of measuring individuals' ability to resist reporting an intuitive incorrect answer (i.e., cognitive reflection). The original version consists of three items (item example presented in the introduction) with each cuing intuitive but wrong response that needs to be detected and corrected in order to arrive to a correct response. In this study, to increase the reliability and response range, we used five different CRT tasks, three from the original Frederick (2005) version and two additional taken from Toplak, West and Stanovich (2014) expansion and Thomson and Oppenheimer (2016) alternate form of the CRT (all items are in in Appendix). Thus, on the CRT one could score anywhere between 0 (if none of the responses were correct) and 5 (if all the responses were correct).

CRT control tasks. Besides the five original tasks, the participants solved five control tasks that differed from the original ones only in the fact that they did not cue intuitive wrong heuristic answers (see Appendix). These tasks were used for calculating the conflict detection indices. Specifically, considering that we timed all the responses, as well as assessed degrees of confidence in the responses, by subtracting the response times and confidences of the control tasks from the ones of the original tasks, we were able to calculate two conflict detection indices, namely the response time difference and the confidence difference.

BBS tasks. BBS tasks assess the susceptibility to belief bias. They pit the believability of a conclusion against its logical validity. In that regard they are similar to the CRT tasks in that, in order to arrive at the correct conclusion, a person must first notice that the believable conclusion, although intuitively receptive and believable, is false. In the present study, we assessed the belief bias using four different syllogisms taken from Markovits and Nantel (1989; see Appendix for all the items). Thus, on BBS, a participant could score anywhere between 0 and 4.

The International Cognitive Ability Resource (ICAR) is a broad cognitive ability assessment tool consisting of four different types of tasks: letters and numbers series, matrix reasoning items, verbal reasoning items and three-dimensional rotation items. In this study we administered a 16 items version consisting of four items of each type. The validation of this measure is reported in Condon and Revelle (2014). The total score was calculated as the sum of correct responses on the 16 items.

The Berlin numeracy test (Cokely, Galesic, Schulz, Ghazal, & Garcia-Retamero, 2012) is a four-question test for assessing numeracy and risk literacy. The questions are designed in a way that they gradually become harder and a person could score anywhere between 0 and 4 on this test. The example of an item is following: “Out of 1,000 people in a small town 500 are members of a choir. Out of these 500 members in a choir 100 are men. Out of the 500 inhabitants that are not in a choir 300 are men. What is the probability that a randomly drawn man is a member of the choir? Please indicate the probability in percent.” The total score was calculated as a sum of correct responses.

Matura score. In order to assess mathematical skills, we asked our participants to report their score on the state matura that most of them had to take in last few years. Similar to the SAT, matura test is an objective standardized test that assesses the knowledge of high school mathematics. There are two different levels of matura that students can take, the easier and the harder one. In order to account for this, we assigned a higher ponder (1.5) to a harder level and computed a total matura score by multiplying the matura grade with the ponder. For example, if a student took a harder level of matura and received a grade of 5, his/her final score would be 7.5 (5 x 1.5). If a student took an easier level and scored 5, his/her total score would be 5 (5 x 1).

Actively open-minded thinking (AOT) refers to adherence to the standard of thinking that includes thorough search relative to the importance of a question, confidence according to the amount and quality of thinking carried out, and consideration of alternatives different to the one we initially favor. In this study we use a 15-item AOT scale that was used in Campitelli and Gerrans paper (2014; e.g. "Changing your mind is a sign of weakness"). It is a self-report scale where participants indicate their level of agreement with items on a six-point scale (1 – strongly disagree to 6 – strongly agree). The total score on this scale is calculated as a mean level of agreement with the items and can be anything between 1 and 6.

Indices of conflict detection. We measured and calculated three different indices of conflict detection on reasoning tasks.

a) Response time. We measured response time in seconds for each of the reasoning tasks' items, from the moment an item would appear on the screen to the moment a participant would write an answer and press "Next" to move to the next question.

b) Response time difference. We calculated a response time difference as a difference between a mean response time for the original reasoning tasks' items and mean response time for the control items. A positive value means that a person spent more time solving an original task than the control one, indicating a conflict detection.

c) Confidence difference. After each of the original and control items, we asked participants how confident they are in their answers on the scale up to 100 %. We calculated a confidence difference as a difference between a mean confidence on the control tasks and a mean confidence on the original tasks. A positive value means that the participants were more confident in their answers when solving control items than the original ones.

Important thing to emphasize is that, as we did not have BBS control tasks (tasks without the lures), we could not calculate response time and confidence differences for BBS. Thus, for BBS we report calculations based solely at response time as a conflict detection indicator.

2.1.3. Procedure

The data were collected in two sessions with approximately six months' time interval between them. In both sessions, participants solved questionnaire on a computer in groups of 20 to 25 participants in the same room under the supervision of the experimenters. In the first session, participants first solved the CRT and CRT control tasks which were presented in a quasi-random order, meaning there were several fixed orders of task presentation and participants were randomly assigned to one of the orders. This was followed by solving the BBS tasks and four items numeracy test before taking a 10-minute break. After the break, participants solved 16 ICAR tasks and a self-report AOT scale. The tasks were presented as a part of a bigger battery of tasks from the judgment and decision-making domain as this study was part of a bigger data collection effort for several different projects and not all collected data are reported here. In the second session, the order of the tasks was somewhat different. Specifically, participants first solved 16 ICAR tasks, followed by the BBS tasks and four numeracy tasks before taking a 10-minute break. After the break participants solved the CRT and CRT control items in quasi-random order followed by a self-report scale of actively open-minded thinking. Similarly as in the first wave, in this wave we also collected additional data that is not reported in this study.

2.2. Results

We are starting this section by presenting the basic descriptive statistics of all the variables as well as the correlations among all the variables. After this, we will first present the results related to the CRT followed by the results related to the BBS. The basic descriptive statistics is given in the Table 1.

Table 1. Descriptive statistics and the reliabilities of the measures used in the study

	Min	Max	Mean	SD	Cronbach α
CRT	.00	5.00	3.16	1.15	.65

CRT control	2.00	5.00	4.66	0.61	.20
BBS	.00	4.00	2.10	1.62	.83
ICAR	1.00	16.00	10.29	3.09	.73
Numeracy	.00	4.00	1.56	1.12	.46
Matura score	1	7.5	4.97	1.59	/
AOT score	1.87	6.00	4.48	0.65	.82
CRT time	6.21	104.20	38.46	15.89	.47
CRT control time	10.47	64.06	30.79	9.69	.51
CRT time difference	-32.09	61.93	7.67	13.61	/
CRT confidence	33.80	100	88.00	12.52	.49
CRT control confidence	38.40	100	90.47	10.67	.54
CRT confidence difference	-45.00	46.00	2.47	11.43	/
BBS time	7.11	51.66	18.19	6.83	.58

Note. CRT = Cognitive reflection test; BBS = Belief bias syllogisms; ICAR = International cognitive ability resource; AOT = Actively open-minded thinking.

Several things are apparent from the Table 1. First, participants found control CRT items to be easier than the original ones (t (505) = 22.60, p = .00, d = 1.00). In fact, great majority of the participants had perfect or near perfect scores on these items but not on the original ones, indicating that they had little problems solving tasks that did not cue wrong responses. Second the difference in difficulty between the two versions of the CRT tasks was reflected in average response times for these tasks where it took participants significantly more time to solve original than the control items (t (505) = 12.68, p = .00, d = 0.56), as well as confidence in their responses where respondents were more confident when solving control items than the original ones (t (505) = 4.86, p = .00, d = 0.22). However, as it is evident from the negative minimum values on the response time difference and confidence difference variables, there were large individual differences where some participants unexpectedly took more time/were less confident solving control tasks than the original tasks while others took less time/were more confident solving control tasks than the original ones.

In sum, it seems that participants on average managed to detect the conflict on the CRT items, although wide ranges of values on the conflict detection indicators show that substantial individual differences exist. Before moving on to the main analyses, we present the correlations among the individual difference variables and conflict indicators in Table 2.

Table 2. Correlations among the study variables

	BBS	ICAR	Numeracy	Matura	AOT	CRT Time	CRT time diff.	CRT conf. diff.	BBS time
CRT	.49**	.51**	.50**	.25**	.21**	.10*	-.01	-.34**	.10*
BBS	1	.39**	.42**	.25**	.28**	-.01	-.05	-.16**	.16**
ICAR		1	.42**	.17**	.22**	.12**	.03	-.10*	.15**
Numeracy			1	.23**	.18**	-.04	-.03	-.12**	.04
Matura				1	.17**	-.07	-.07	-.02	-.07
AOT					1	.10*	.06	-.01	.05
CRT time						1	.80**	.12**	.30**
CRT time diff.							1	.29**	.16*
CRT conf. diff.								1	.00
BBS time									1

Note. CRT = Cognitive reflection test; BBS = Belief bias syllogisms; ICAR = International cognitive ability resource; AOT = Actively open-minded thinking; CRT time = Cognitive reflection test response time; CRT time diff. = Cognitive reflection test response time difference; CRT conf. diff. = Cognitive reflection test confidence difference; BBS time= Belief bias syllogisms response time.
* $p < .05$; ** $p < .01$

As can be seen from the Table 2, the correlations between the two time-based indicators of conflict detection are quite high (r = .80) which is unsurprising since one is derived from the other. This gives additional support to our assumption that the response time actually captures conflict detection, however imperfectly. This is important as a prolonged response time by itself does not mean that a person has actually detected a conflict and engaged in corrective deliberation, but could just mean that he/she was careful on each item, meaning that the response time does not necessarily imply conflict detection (e.g. Bago & De Neys, 2017). However, a high correlation between response time and response time difference, that is purer measure of conflict detection, testifies that response time, at least in this study, can be taken as a proxy of conflict detection. On the other hand, the correlations between the confidence difference indicator and the two time-based indicators are substantially lower (*r* = .12 and *r* = .29). This shows that the confidence difference indicator is somewhat distinct from the ones based on response times and confirm the importance of using different indicators of conflict detection for a more complete view.

Most of the conflict detection indices were poorly related to accuracy both for the CRT and the BBS. It seems that conflict detection is relatively poor predictor of accuracy. However, this is not that surprising from the point of view of the hybrid dual-process model and logical intuitions which posits that these relationships will be moderated by the mindware instantiation, or the strength of logical intuitions. For example, for those with very strong logical intuitions (evidenced by the high scores on knowledge, abilities and dispositions measures), we would expect that the conflict detection is a poor predictor of accuracy, whereas for those with somewhat weaker logical intuitions (e.g. comparable in strength with incorrect intuition cued by the task characteristics) we would expect a positive correlation between conflict detection and accuracy. We will explore these interactions, therefore, in our main analyses.

Although these were not the focus of the present study, it is worth noting that the correlations among the CRT, intelligence and numeracy are positive and of medium magnitude as it is often the case in the literature (e.g. Campitelli & Gerrans, 2014; Frederick, 2005; Welsh, Burns, & Delfabbro, 2013), and the one between the CRT and math skills is somewhat smaller but still significant. Small and positive correlation was also recorded between the CRT and AOT, which is also in line with previous findings (e.g. Campitelli & Gerrans, 2014; Toplak, West & Stanovich, 2011). The pattern of BBS correlations with these variables closely mirrors the CRT pattern of correlations. Furthermore, very low correlations were observed between the conflict detection indices and intelligence, numeracy, matura score and AOT. However, it is interesting to note positive correlation between ICAR and response time both for CRT and BBS, showing that more intelligent people took somewhat more time to solve these tasks. Finally, numeracy was somewhat negatively correlated with confidence difference on CRT tasks. This suggests that the skepticism in one’s responses was indicative of lower numeracy when solving the CRT tasks.

2.2.1. The CRT analyses

2.2.1.1. Response time as a conflict detection index

We conducted our main analyses at the level of the individual trials, meaning that the trials, and not participants, were the main unit of analysis. In this way, we effectively increased the "sample size", thereby increasing the statistical power, and ensured that the effects of conflict detection can be analyzed for correct and incorrect trials separately. To answer our main research question (how the four types of responding – correct non-detections, correct detections, incorrect non-detections, incorrect detections - reflect abilities, knowledge and dispositions), we had to divide our trials based on the accuracy and probability of conflict detection. As we explicated before, these different types of responses should be indicative of the mindware development and the corresponding strengths of logical intuitions. To differentiate between probable conflict detections from non-detections, we combined the response times with confidence differences between the control and original item. The logic we followed here is that if a person responded relatively quickly on the reasoning task AND showed no confidence difference between the response on the control vs. original item, then that person probably did not detect the conflict on that trial. This would be an equivalent to participants whose initial, fast response in a two-response paradigm is correct and who show very little difference in confidences in initial responses between control and original items. These participants should have the most developed mindware and the strongest logical intuitions. However, to define our categories, we still had to decide on the cut-off point between relatively fast and other responses. The logic should be the following: the lower the response time, the lower the chance of conflict detection, given no confidence difference. However, as this is always an arbitrary decision, it would also be useful to report results for at least two different cut-off points to explore whether this change in arbitrary decision substantially affected the conclusions. If the conclusions remain similar across cut-off points, we can be more confident that our results are reliable and not much affected by the arbitrariness of our decisions.

We have decided to make two cut-off point for response times that separate the a) 10% of the fastest, and b) 20% of the fastest respondents from the rest. As we said earlier, the lower we set the threshold, the greater chance that the response was given with very little or no conflict detection[1]. Therefore, we

[1] In this case, our 10% cut-off point is only slightly higher than the average reading time for CRT items that we obtained in a small pre-study (N = 18) that we conducted prior to our Study 2. In this pre-study, four of the five CRT items were the same as in this study (all but the fourth item) so we could make the comparisons. The smallest difference between the 10% threshold and average reading time was for CRT 2 item (0.54 seconds), and the largest was for CRT 3 item (3.19 seconds). Therefore, this 10%

classified as non-detection those trials on which the response times were among 10% and 20% of the fastest respectively, and on which there was no confidence difference in responses between the control and original item. Those trials where the confidence difference between the control and original item was negative (meaning that the person was more confident in his/her response on the original item than on the easy, control item) were discarded from further analyses as these cases are very hard to logically explain. The frequencies of the trials according to accuracy/detection are shown in the Table 3, both for the 10% and for the 20% threshold.

Table 3. Frequencies of the CRT trials based on accuracy and conflict detection for two different cut-off points for conflict detection, 10% and 20% of the fastest responses.

	N (10% fastest)	N (20% fastest)
Correct non-detection	85	173
Correct detection	1132	1044
Incorrect non-detection	79	152
Incorrect detection	710	637
Total	2006	2006

What is the most apparent from this table is that the intuitive correct responding (correct non-detection) is substantially rarer than deliberate correct responding (correct detection). This differs from most of the findings from the two-response studies that show that, when the correct responses are given, they are mostly given intuitively. This either means that our cut-off points were quite strict, leaving plenty of non-detection trials categorized as detection ones, or that majority of people do not respond intuitively if they are not explicitly asked to. However, even if our cut-off points were too strict, we would not

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threshold obviously did not allow our participants to do much thinking, especially if we take into account that they were not instructed to read without pauses (as they were in the pre-study). Given this, it can be argued that the 10% threshold is overly conservative – as our participants did not have the instruction to read the items quickly, there is high chance that those that would be intuitively correct in two-response paradigm would end up being classified as conflict detectors here. Therefore, if we find, for example, that the correct non-detectors were significantly smarter and better at math than the correct detectors, these differences would probably be even more expressed have we expanded the threshold. It also gives us additional argument to use the 20% threshold in addition to the 10% threshold: not only we will see how this decision affects the results, but by expanding the threshold, we will probably categorize those that would respond intuitively correctly a bit more precisely.

argue that this is too serious problem for our purposes. As we said earlier, by making this cut-off stricter, we increase the chances that most of the correct non-detection responses is correctly classified, and that is what matters the most if we want to see the trends in individual differences between those with quite strong logical intuitions and the rest.

To examine whether individual differences in cognitive ability, numeracy, math skills and thinking disposition underpin the four response types, we calculated one-way mixed effects ANOVAs for each of the dependent variables, with four response categories as fixed effects and CRT items as random effects. We did the same analyses for 10% and 20% fastest participants as the cut-off for detection.

With 10% threshold for conflict detection, ANOVA was significant for each of the dependent variables: ICAR (F (3, 17187) = 111.22, p < .001, partial $\eta 2$ = .95), numeracy (F (3, 13644) = 48.89, p < .001, partial $\eta 2$ = .92), AOT (F (3, 15870) = 9.92, p = .001, partial $\eta 2$ = .65) and matura score (F (3, 15312) = 23.19, p < .001, partial $\eta 2$ = .82). This is not surprising as generally those that are successful on CRT tasks are shown to be more intelligent, knowledgeable in math and more prone to analytical thinking. What is more interesting is whether there were differences between probable conflict detections and non-detections on correct and incorrect trials. In this regard, among the correct trials, there was generally a trend of higher scores on the individual differences variables for correct non-detection trials than for correct detection trials, although this difference was significant only for numeracy (t = 3.08, p = .002, d = .35), but not for other measures. Among the incorrect trials, there were no significant differences on individual differences variables between the detectors and non-detectors.

With 20% threshold for conflict detection, ANOVA was again significant for each of the dependent variables: ICAR (F (3, 14503) = 57.75, p < .001, partial $\eta 2$ = .92), numeracy (F (3, 14641) = 70.19, p < .001, partial $\eta 2$ = .94), AOT (F (3, 14864) =7.00, p = .004, partial $\eta 2$ = .59) and matura scores (F (3, 14781) = 17.24, p < .001, partial $\eta 2$ = .78). When comparing conflict detections and non-detections, the trends are basically the same as with 10% threshold. Correct non-detection trials were always related with somewhat higher scores on individual differences variables than correct detection trials. Again, there was a significant difference for numeracy (t = 5.39, p < .001, d = .44), but this time also for ICAR (t = 2.18, p = .030, d = .18), although this difference was rather small. Among the incorrect trials, the only significant difference between the conflict detection and non-detection trials was for ICAR with conflict detection trials being associated with higher scores than non-detection trials ($t = 3.55$, $p < .001$, $d = .32$).

We conducted a sensitivity analysis and found that we had 80% power to detect relatively small differences ($d = 0.23$ and $d = 0.25$) between our correct detectors and non-detectors and incorrect detectors and non-detectors respectively, given the Type I error of $\alpha = .05$, indicating that we did not have a problem with low statistical power. As the trends for 10% and 20% threshold were very similar, we have plotted these effects for 20% threshold and have shown them in the Figure 1.

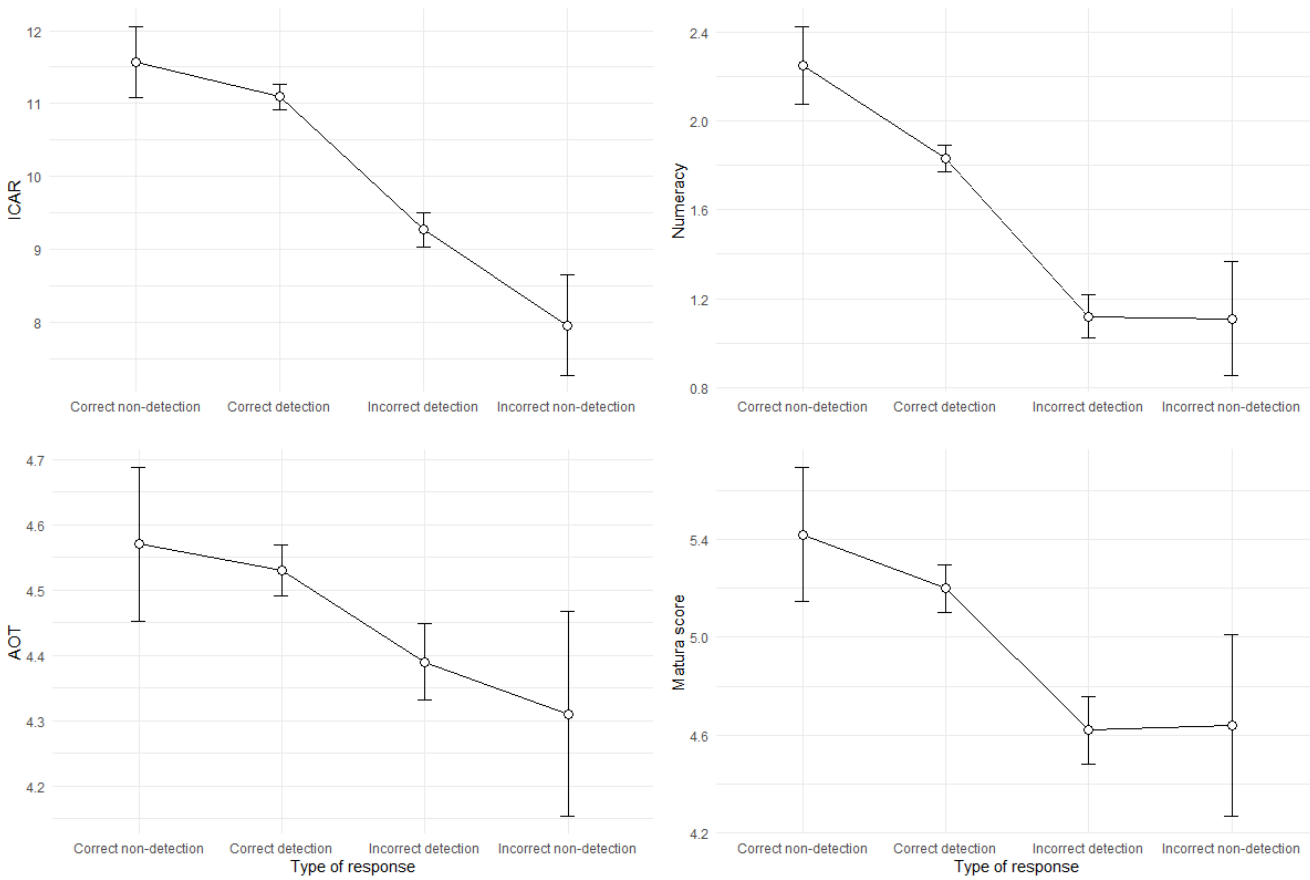

Figure 1. Differences in cognitive abilities, numeracy, actively open-minded thinking and matura score between the four response types on CRT tasks based on response time and confidence differences as conflict detection indicators

2.2.1.2. Response time difference as a conflict detection index

Response time difference is calculated as a difference between the response time on original item and response time on the control item. Positive values here should indicate a conflict detection, while no difference should indicate lack or very weak conflict detection. The problem here is that, expectedly, there were virtually none of the cases where the difference between the response times on original and control item was exactly 0 seconds. Therefore, we again faced a need to make an arbitrary decision on where to draw the line for conflict detection, or more precisely, how wide should our interval around 0 seconds be. For example, a person that generally solved the original and the control items at the same speed and with the same confidence, therefore not showing any conflict detection signs, will probably sometimes just by chance spend somewhat more time on control than on the original items, having a negative response time difference. However, this negative value should not be too large as there is no rational reason for why someone would take much more time to solve control than original item. In other words, large negative values are hard to explain as they are probably result of issues such as technical problems or laps of attention.. Therefore, large negative values are best to be discarded from further analyses. This brings us back again to our arbitrary decision. With this decision, the logic should be the same as with response time – the narrower the interval, the higher chance that it will mostly contain trials on which participants showed very little signs of conflict detection, especially in conjunction with no confidence decrease in responses from control to original item. We have again decided to go with two different cut-off points, or in this case intervals, to see whether and how this decision affects our results. These intervals are +/- 2 and +/- 3 seconds. As we noted earlier, these are arbitrary decisions, but we believe that these intervals are conservative. For example, the median response time for our control CRT items ranged between 13.8 seconds and 44.2 seconds. The two or three seconds difference in response time between the original and control item represent only a small fraction of time that it took to read and solve easy control items. Therefore, it is plausible that someone who solved these items roughly at the same speed would sometimes end up solving one item up to two or three seconds faster or slower compared to the other item.

Thus, those trials which did not show confidence difference in responses between control and original items AND whose response time differences were between -2 and 2 seconds (more strict classification) and between -3 and 3 seconds (less strict classification) respectively were classified as conflict non-detection trials. In the Table 4, we are showing the frequencies of trials in each of our four categories, both for +/- 2 and +/-3 seconds cut-off interval. In comparison with Table 3, there are substantially less valid trials for analysis. The reason for this is that when using response time as conflict detection indicator (reported in the Table 3), we discarded only the trials that showed negative confidence differences, while with response time difference as conflict detection, we discarded both those with negative confidence differences and those with overly large negative response time differences (more than -2 and -3 seconds respectively).

Table 4. Frequencies of the CRT trials based on accuracy and conflict detection for two different cut-off intervals for conflict detection, +/- 2 seconds and +/- 3 seconds.

	N (+/- 2 seconds)	N (+/- 3 seconds)
Correct non-detection	122	184
Correct detection	730	705
Incorrect non-detection	49	90
Incorrect detection	478	456
Total	1151	1435

Again, we calculated one-way mixed effects ANOVAs for each of the dependent variables, with four response categories as fixed factor and CRT items as random factor. With +/- 2 seconds as cut-off interval, ANOVAs were significant for each of the dependent variables: ICAR (F (3, 15846) = 37.00, p < .001, partial $\eta 2$ = .88), numeracy (F (3, 14661) = 31.61, p < .001, partial $\eta 2$ = .87), AOT (F (3, 15039) = 64.45, p = .020, partial $\eta 2$ = .47) and matura (F (3, 14699) = 9.19, p = .001, partial $\eta 2$ = .65). We were again more interested to see whether there were any differences between the detection and non-detection trials, both among the correct and incorrect trials. Similarly as with the response times as the conflict detection indicator, the trend was always in the direction of higher scores on dependent variables underpinning correct non-detection trials in comparison to correct detection trials. However, these effects reached significance only for numeracy (t = 2.54, p = .011, d = .25). For incorrect trials, there were no significant differences between the conflict detection and non-detection trials.

With +/- 3 seconds as cut-off interval, ANOVAs were again significant for each of the dependent variables: ICAR (F (3, 14937) = 25.90, p < .001, partial $\eta 2$ = .84), numeracy (F (3, 14822) = 37.20, p < .001, partial $\eta 2$ = .88), AOT (F (3, 15967) = 5.56, p = .008, partial $\eta 2$ = .51) and matura (F (3, 14449) = 8.81, p = .001, partial $\eta 2$ = .65). As it was the case with the +/- 2 seconds cut-off interval, the correct non-detections were associated with significantly numeracy scores than correct detections (t = 4.49, p <

.001, *d* = .37). Again, same as before, there were no significant differences among incorrect trials between the conflict detection and non-detection trials.

The sensitivity analyses showed that this time we were 80% powered to detect the difference of *d* = 0.23 between the correct detection and non-detection trials and the difference of *d* = 0.32 between the incorrect detection and non-detection trials. The effects for +/- 3 seconds cut-off interval are shown in the Figure 2.

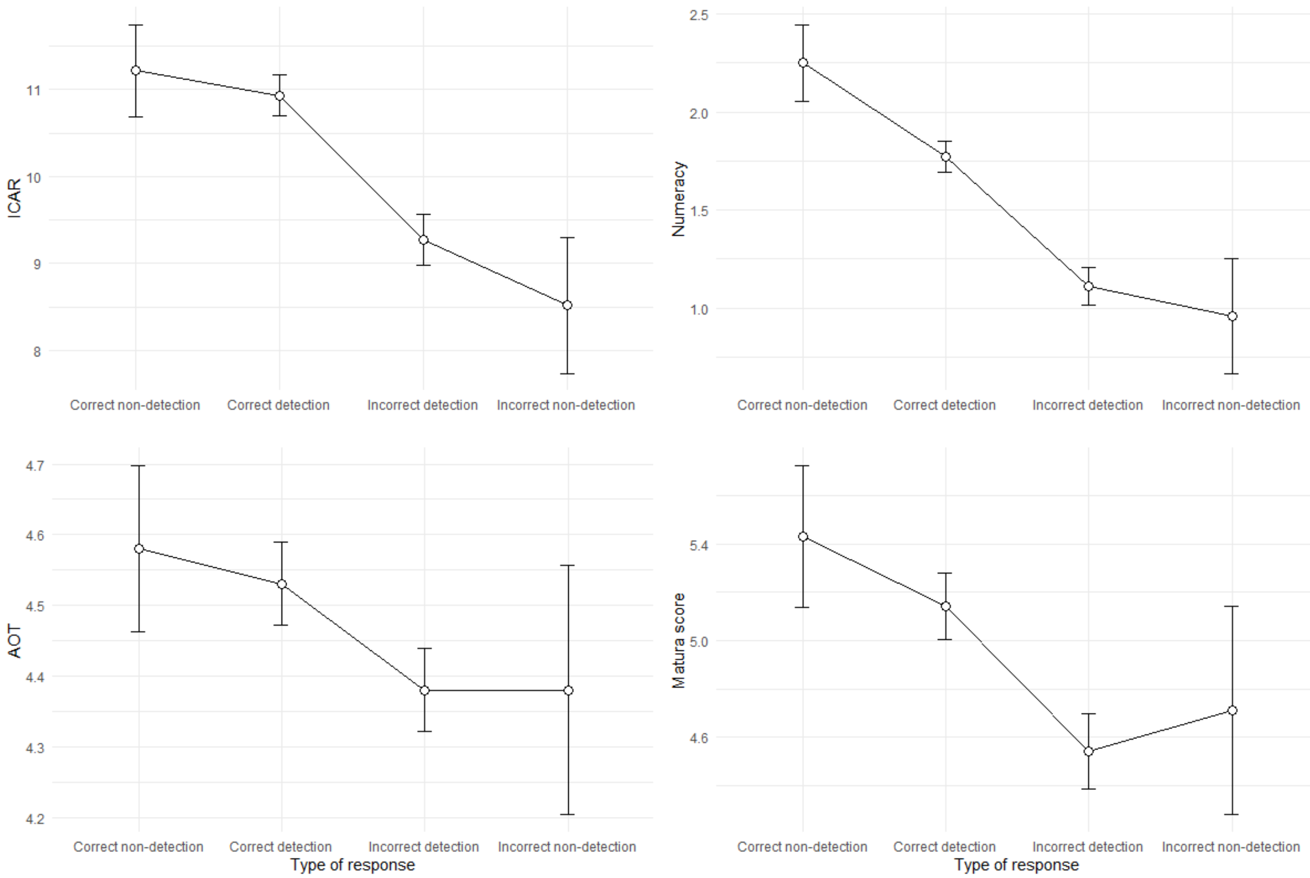

Figure 2. Differences in cognitive abilities, numeracy, actively open-minded thinking and matura score between the four response types on CRT tasks based on response time differences and confidence differences as conflict detection indicators

2.2.2. BBS analysis

As we did not have appropriate control items for the BBS items, we could only rely on the raw response times as conflict detection indicators. As explained before, raw response times have several limitations as a conflict detection indicator. However, by using stricter thresholds for conflict detection, these limitations are somewhat mitigated[2]. As with CRT response time analyses, we again used the two cut-off points: 10% and 20% of the fastest[3]. We are showing the frequencies of BBS trials across our four categories for both cut-off points in the Table 5.

Table 5. Frequencies of the BBS trials based on accuracy and conflict detection for two different cut-off points for conflict detection, 10% and 20% of the fastest responses.

	N (10% fastest)	N (20% fastest)
Correct non-detection	78	155
Correct detection	983	906
Incorrect non-detection	126	248
Incorrect detection	837	715
Total	2024	2024

Again, we calculated one-way mixed effects ANOVAs for each of the dependent variables, with four response categories as fixed factor and CRT items as random factor. With 10% fastest as cut-off point, ANOVAs were significant for each of the dependent variables: ICAR (F (3, 9296) = 41.56, p < .001,

[2] Here, we could not combine response times with confidence differences, but we compared the classifications for CRT responses when only response times were used to those when they were used in conjunction with confidence differences. If there is a significant overlap between the categories, we can conclude that classifying trials based solely on (very fast) response times can be satisfactory, although imperfect, proxy for conflict detection. For the CRT trials, the overlap was substantial for both cut-off points. For example, with the 10% cut-off point, out of 88 trials categorized as correct non-detections based on response time, 85 was also classified in this category when response time was used in conjunction with confidence difference, with only 3 being classified as correct detectors. The overlap was somewhat lower, but still relatively high, for incorrect non-detection trial. Out of 115 incorrect non-detections based on response times, 79 were in that same category based on response times AND no confidence difference criterion. Therefore, low response times by themselves seem to be relatively good, although not perfect, indicators of non-detection.

[3] When compared with BBS reading times from the pre-study to Study 2, the 10% cut-off point was only slightly higher than the average reading time (ranging from only 0.01 seconds for item 3 to 1.72 seconds for item 1). Therefore, the fastest 10% did not have much time, if any, for conflict detection and deliberate correction of erroneous first response. Thus, in this group, if there were instances of conflict detection, it was probably very weak, meaning that these responses should have predominately been given by those with very strong (if they responded correctly) or very weak (if they responded incorrectly) logical intuitions.

partial $\eta 2$ = .93), numeracy (F (3, 9717) = 120.21, p < .001, partial $\eta 2$ = .97), AOT (F (3, 10904) = 121.00, p < .001, partial $\eta 2$ = .97) and matura (F (3, 9210) = 11.59, p = .002, partial $\eta 2$ = .79). There were no significant differences on dependent variables between the correct detection and non-detection trials, and the only significant difference between the incorrect detection and non-detection trials was for the ICAR score (t = 2.31, p = .021, d = .22) where the detection trials were associated with higher ICAR scores than non-detection trials.

The results were practically identical for the 20% cut-off point. ANOVAs were again significant for each of the dependent variables: ICAR (F (3, 11086) = 177.65, p < .001, partial $\eta 2$ = .98), numeracy (F (3, 9630) = 73.65, p < .001, partial $\eta 2$ = .96), AOT (F (3, 10470) = 68.41, p < .001, partial $\eta 2$ = .95) and matura (F (3, 10023) = 38.11, p = .001, partial $\eta 2$ = .92). Again, there were no significant differences on dependent variables between the correct detection and non-detection trials, and the only significant difference between the incorrect detection and non-detection trials was for the ICAR score (t = 2.67, p = .008, d = .20) where the detection trials were associated with higher ICAR scores than non-detection trials.

This time, we were powered 80% to detect the effect size of d = 0.24 between correct detection and non-detection trials and the effect size of d = 0.21 between incorrect detection and non-detection trials with the Type I error of α = .05. Thus, any meaningful difference between these trials would have probably been detected by our analyses, suggesting that the statistical power was satisfactory. These effects are plotted in the Figure 3.

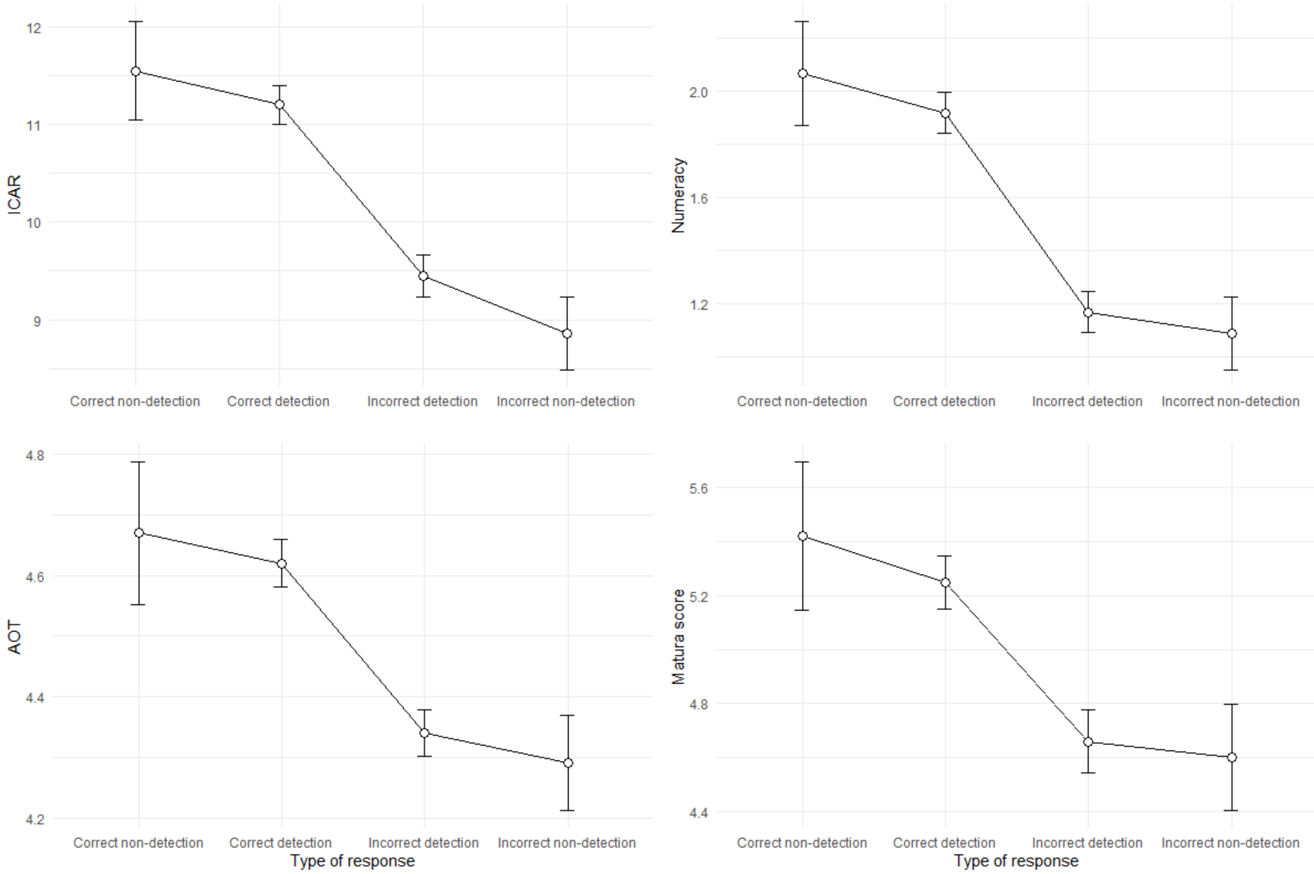

Figure 3. Differences in cognitive abilities, numeracy, actively open-minded thinking and matura score between the four response types on BBS tasks based on response time as conflict detection indicator

2.3. Study 1 discussion

In Study 1, we tried to classify responses on CRT and BBS items based on their accuracy and probability of conflict detection. If the trial had low probability of conflict detection and was accurate, we classified it as correct non-detection. Conversely, if it was inaccurate, we classified it as incorrect non-detection. If there were signs of conflict detection, based on their accuracy, trials were categorized as either correct or incorrect detections. We obtained some interesting differences on cognitive ability, numeracy, disposition towards actively open-minded thinking and mathematical knowledge score between these trials. These effects are shown in Figures 1, 2 and 3. The categories on the x-axis are arranged so that they reflect a mindware instantiation continuum – the first category on the left (correct non-detection) should reflect the most developed mindware and the strongest logical intuition, while the last category (incorrect non-detection) reflects the least developed mindware and the weakest logical intuition. The general pattern seen on the figures, both for CRT and BBS items, is that as the supposed mindware quality/strength of logical intuition reflected in the type of trials decreases, so do the most of individual differences variables. In doing so, the biggest differences are always between the correct and incorrect detectors, indicating perhaps that these individual differences are important both for conflict detection, but also for deliberate correction through doing explicit calculations that draw on cognitive capacities and math knowledge. This is basically what a classical dual-process view or Stanovich et al. (2016) tripartite theory would suggest.

However, there were also some interesting differences regarding conflict detection/non-detection within incorrect and correct trials. The most consistent finding here was the role of intelligence in the degree of mindware among the incorrect responders. Higher intelligence was consistently related with the ability to detect the conflict even among those that did not manage to actually solve the problems correctly. This perhaps means that there exists some minimal threshold of intelligence below which a person did not manage to develop the mindware relevant for these kinds of tasks even to be able to "feel" that something was wrong with their responses. This is perhaps due to lower capacity people not having interest and drive to engage in these types of tasks, therefore not being experienced in it. Or it could be due to these people not being able to drive meaningful conclusions and insights from these types of tasks and thus not being able to develop relevant intuitions that could help them solve these and similar tasks.

Among the correct trials, although the trend of the non-detection trials being related to higher scores than the detection trials was present, neither intelligence nor thinking dispositions were that important. Actually, for BBS, none of measured individual difference variables were much important judging from mostly nonsignificant results. However, numeracy was consistently the only variable significantly differentiating between the correct detection and non-detection CRT trials. The conclusion that could be drawn from these results is that, while cognitive abilities are important for mindware instantiation, they are not sufficient for developing strong and quality mindware and expert intuitions. To make this "extra step", some kind of specialized knowledge is needed. Cognitive abilities and dispositions, although perhaps necessary for gaining this type of knowledge, are not sufficient. It probably takes a mix of abilities, motivation and opportunity to engage with these types of tasks to obtain knowledge and experience rich enough to allow for very strong and correct intuitions. For BBS tasks, our individual differences variables did not capture this knowledge, but for CRT it seems that the numeracy as we measured it was exactly the type of knowledge and skills that reflects expertise needed for success. This aligns nicely with a number of studies showing very large correlations between the CRT and numeracy scores (e.g. Erceg, Galić & Ružojčić, 2020; Finucane & Gullion, 2010; Primi, Morsany, Chiei & Donati, 2016; Welsh, Burns & Delfabbro, 2013). In sum, each of our individual differences variables was important in developing quality mindware and strong logical intuitions, with intelligence being a prerequisite for developing minimal mindware, and strong numerical abilities a necessity for developing very strong mindware and logical intuitions for CRT problems.

However, as we already suggested, a single-response paradigm has substantial drawbacks in terms of ability to capture the conflict detection and deliberate correction processes. The main problem was that the participants were not instructed to read the items quickly and respond quickly and intuitively. This could have resulted in participants mostly taking their times to read the problems and responding carefully, but also in inconsistencies in reading times on different items (i.e. randomly taking more or less time depending on the concentration, boredom, other thoughts that might have occurred during reading, etc.). This first drawback significantly invalidates raw response times as conflict detection indicator. We tried to mitigate this problem by substantially lowering the threshold to capture mostly those that did respond quickly and intuitively. However, this introduced further problem – we probably classified many of those that would respond quickly and intuitively correctly (had they been told to do so) as conflict detectors, possibly raising the average scores on our individual difference variables in the correct detection group and thereby blurring the differences between the correct non-detection and detection group. The second drawback is more related to time difference as conflict detection indicator. The inconsistencies in response times due to lack of instruction to read the items and respond to them in a consistent way probably resulted in high number of misclassifications due to luck/randomness. This again might have blurred the differences between our groups.

In response to these problems, we have conducted a second study, but this time based on the two-response paradigm. In this paradigm, participants responded two times on the same items: first with substantially limited time and cognitive resources, followed by classical responding without any kind of limitations. This way it is possible to differentiate between correct non-detections and detections in a much more precise way.

3. Study 2

The goal of the second study was, therefore, to investigate individual differences in abilities, knowledge and dispositions that underpin different types of responses on reasoning tasks using the two-response paradigm. This paradigm allows us to more precisely differentiate between those that manage to respond correctly even when time and cognitive resources are severely limited from those that manage to respond correctly only when given enough time think more carefully about the problem. The former type of responses is usually coded as “11”, meaning that the participant responded correctly both in fast and slow condition. Participants who respond in this way probably have highly developed mindware and very strong logical intuitions (substantially stronger than incorrect intuitions) that allow them to respond intuitively correctly and in doing so to detect very little conflict. The latter type of responses is usually coded as “01” as the first response was incorrect and the second was correct. Participants who respond in this way probably have somewhat less developed mindware and weaker logical intuitions, resulting in them first giving incorrect response, but then detecting the conflict and correcting the erroneous intuition. Finally, the two-response paradigm also allows for detecting the third group of those that do not manage to respond correctly even after they spend time and cognitive resources on the problem (coded as “00”). This group probably has the least developed mindware and weakest logical intuitions, much weaker than the incorrect intuition. These differences in types of responding should be underpinned by differences in cognitive abilities, knowledge and thinking dispositions, and these differences are the focus of this study.

3.1. Methods

3.1.1. Participants

A total of 83 subjects participated in Study 2. Participants were university students from different University of Zagreb faculties, mostly females (N = 56), with mean age of M = 22.8 (SD = 3.63).

3.1.2. Instruments

In this section we will describe the instruments that we used in Study 2 that were either new or different from the ones we used in Study 1.

Cognitive reflection items (CRT). In Study 2, we used seven CRT-like items (see Appendix): three from the original CRT (Frederick, 2005), two from the Thomson and Oppenheimer (2016) version, one from the Primi et al. (2016) version and one related to illusion of linearity from Putarek and Vlahović-Štetić (2019). There were four response options for each item, containing a correct response, intuitive incorrect response and two other incorrect responses. Participants' task was to choose the response thy thing is a correct one. The total score was calculated as the average number of correct responses on the seven items.

Belief-bias syllogisms (BBS). One of the drawbacks of the Study 1 was also the fact that we used only the BBS items with believable, but logically incorrect conclusions. In this study, we balanced the item pool by adding the three BBS items with unbelievable, but logically correct conclusions to the four believable, but logically incorrect items, totaling seven BBS items (see Appendix). All items were taken from Markovits and Nantel (1989) study. The total score was calculated as the average number of correct responses on the seven items.

Actively open-minded thinking (AOT) scale. AOT scale was also different from the one we used in Study 1. This time, we opted for the currently recommended 10-item AOT scale (http://www.sjdm.org/dmidi/Actively_Open-Minded_Thinking_Beliefs.html). Participants rated their level of agreement with these items on a five-point scale (the items are available in the Appendix), and the total score was calculated as the average of ratings on 10 items after some of the items were recoded such that higher scores indicate higher AOT.

Need for cognition (NFC) scale. To measure NFC, we used a short, five-item scale (see Appendix for items; Caccioppo & Petty, 1982). Participants rated their level of agreement on a five-point scale, and the total score was calculated as the average of the ratings, after some items were recoded such that higher ratings indicate higher NFC.

Apart from these, we also measured intelligence, numeracy and matura score, but these instruments were the same as in the Study 1.

3.1.3. Procedure

The study was conducted online using the Limesurvey software. Prior to solving the questionnaire, participants were gathered in small groups for a live online meeting in which an experimenter guided participants through all the instructions. The instructions were also written within the survey, but we insisted on a live meeting to make sure that all the participants read and properly understood them. Experimenter and participants went through several survey pages that contained the instruction together, with experimenter reading the instructions aloud, and answering participants questions.

The exact wording for general and specific CRT and BBS instruction can be found in the Supplementary material. In short, participants were told that they are about to solve some reasoning tasks, but that they will solve them twice. Both for CRT tasks and BBS tasks, they were told that they will first solve the tasks with severe time limit and burdened capacity for deliberation (by memory task) and immediately after that, in the slow condition, they will solve the same task again, only this time without any constraints. Following the instruction, participants solved two training tasks to see how the whole process looks like and to get the feeling of how little time they had to read and respond in fast situation. There were several steps in this solving process. Participants were first presented with a 3 by 3 matrix that contained four black dots for five seconds (see Supplementary material for an example of this matrix). They were instructed to memorize the pattern as they will be asked to recognize it among four different matrices later. Immediately after the period of five seconds ran out, participants were automatically transferred to next page that contained a CRT item with a time limit. Time limits were set on the basis of average reading time for these items obtained through a small pre-study (N = 18)[4]. Once the time was up, participants were again automatically transferred to next page where we asked them

[4] As the feedback from the several "testing" participants was that the time limits were too short and that there was too little time to read the majority of the items, we increased the time limits to be slightly higher than the pre-study reading average. This was particularly the case for CRT items, and the reason for this mismatch is probably because in the pre-study we did not show participants four response options, but only the item stems, asking them to click "next" once they read the item. In the "real" survey, there were four response options, so participants had to read all the options before responding and this required some additional time.

how confident they were in their first response (0% - 100%). This was not timed. After indicating the degree of confidence in their results, participants had to recognize the matrix they memorized among the four options. Once they responded to this memory task, they moved on to the next page where they responded to the same CRT item, only this time without the time limit. Finally, once they chose their response, they were again asked to indicate their degree of confidence in their second response. This sequence was the same for CRT and BBS items. Participants always solved CRT items first and BBS items after. After solving seven CRT and seven BBS tasks in fast and slow conditions, participants solved 16 ICAR items, four numeracy items, 10-item AOT scale and five-item NFC scale. The survey ended with several demographic questions.

3.2. Results

We will first present descriptive statistics of and correlations between our focal variables at the participant level. The main analysis of differences between the three types of responses ("11", "01", "00") was done at the item level, analogous to the analyses from the Study 1. We note here that one more response type is theoretically possible in two-response paradigm and that is "10" response (intuitive correct and then deliberate incorrect response). However, these types of responses are nonsensical and, expectedly, were extremely rare in our case. Among CRT trials, there were only six out of 499 valid trials (meaning the trials that were given within the time limit) that were responded in this way, while among the BBS trials there were none of the "10" cases. Therefore, we discarded the six CRT trials and conducted further analyses on three remaining categories. Descriptive statistics for our focal variables are shown in the Table 6, and the correlations among our focal variables in the Table 7.

Table 6. Descriptive statistics of Study 2 focal variables

	M	SD	Min	Max	Cronbach α
CRT fast	0.40	0.26	0	1	.66
CRT slow	0.66	0.29	0	1	.77
BBS fast	0.59	0.26	0	1	.76
BBS slow	0.65	0.29	0	1	.83

ICAR	10.37	3.04	0	16	.75
NUM	1.60	1.23	0	4	.56
AOT	3.98	0.41	2.70	5	.50
NFC	3.41	0.81	1.40	5	.83
Matura	5.01	1.25	2	7.50	/
CRT fast conf.	59.16	19.73	2.86	95.71	.58
CRT slow conf.	90.78	13.14	10.00	100	.79
CRT slow time	29.37	18.54	9.95	104.20	.68
BBS fast conf	75.15	20.24	1.43	100	.81
BBS slow conf.	92.01	13.67	9.29	100	.91
BBS slow time	14.33	6.40	5.60	35.27	.57

Note. CRT fast = Cognitive reflection test average score in the fast-responding situation; CRT slow = Cognitive reflection test average score in the slow-responding situation; BBS fast = Belief bias syllogisms average score in the fast-responding situation; BBS slow = Belief bias syllogisms average score in the slow-responding situation; ICAR = International cognitive ability resource; NUM = numeracy; AOT = Actively open-minded thinking; NFC = Need for cognition; CRT fast conf. = Average confidence in responses on cognitive reflection tasks in the fast-responding situation; CRT slow conf. = Average confidence in responses on cognitive reflection tasks in the slow-responding situation; CRT slow time = Average response time on cognitive reflection tasks in the slow-responding situation; BBS fast conf. = Average confidence in responses on belief bias syllogisms in the fast-responding situation; BBS slow conf. = Average confidence in responses on belief bias syllogisms in the slow-responding situation; BBS slow time = Average response time on belief bias syllogisms in the slow-responding situation.

Table 6 shows that the pattern of the results generally aligns with the expectations. The participants were better at reasoning tasks in the slow situation, when they had time to think about their responses, than in the fast situation, both for CRT items ($t = 9.07$, $p < .001$, $d = 1.00$) and BBS items ($t = 3.97$, $p < .001$, $d = .37$). This was accompanied by generally lower confidences in responses when the time was limited compared to the “slow” condition ($t = 17.94$, $p < .001$, $d = 1.98$ for CRT and $t = 11.61$, $p < .001$, $d = 1.29$).

Table 7. Correlation among the Study 2 focal variables

	CRT s.	BBS f.	BBS s.	ICAR	NUM	AOT	NFC	Matura	CRT f. c.	CRT s. c.	CRT s. t.	BBS f. c.	BBS s. c.	BBS s. t.
CRT f.	.56**	.25*	.31**	.33**	.54**	.05	.30**	.28**	.33**	.20	-.18	.08	.14	.12
CRT s.		.42**	.48**	.60**	.60**	.13	.20	.49**	.17	.28*	.27*	.05	.13	.38**
BBS f.			.83**	.43**	.40**	.40**	.20	.39**	-.02	-.01	.17	-.08	.00	.10
BBS s.				.41**	.50**	.33**	.18	.43**	.00	-.02	.19	-.10	.01	.30**
ICAR					.48**	.22*	.24*	.42**	.22	.32**	.22	.22*	.30**	.22*
NUM						.31**	.22*	.36**	.22*	.26*	.13	.09	.22	.33**
AOT							.26*	.05	.20	.16	.11	.06	.06	.10
NFC								.14	.20	.31*	-.09	.16	.21	-.06
Matura									.22	.22	.02	.06	.09	.19
CRT f. c.										.59**	-.14	.50**	.39**	-.03
CRT s. c.											-.02	.57**	.69**	.13
CRT s. t.												-.02	.07	.37**
BBS f. c.													.77**	-.29**
BBS s. c.														-.06

Note. CRT f. = Cognitive reflection scores in the fast-responding situation; CRT s. = Cognitive reflection scores in the slow-responding situation; BBS f. = Belief bias syllogisms scores in the fast-responding situation; BBS s. = Belief bias syllogisms scores in the slow-responding situation; ICAR = International cognitive ability resource; NUM = Numeracy; AOT = Actively open-minded thinking; NFC = Need for cognition; CRT c. f. = Average confidence in responses on cognitive reflection tasks in the fast-responding situation; CRT c. s. = Average confidence in responses on cognitive reflection tasks in the slow-responding situation; CRT t. s. = Average response time on cognitive reflection tasks in the slow-responding situation; BBS c. f. = Average confidence in responses on belief bias syllogisms in the fast-responding situation; BBS c. s. = Average confidence in responses on belief bias syllogisms in the slow-responding situation; BBS t. s. = Average response time on belief bias syllogisms in the slow-responding situation.

There are several interesting findings apparent in the Table 7. First, there were very high correlations between first and second responses, especially for BBS items. This indicates that on both tasks, when the correct response was given, it was very often given already in the fast condition. Second, not surprisingly, CRT and BBS scores in the slow condition were positively correlated with all of our individual difference variables, with some of these correlations being quite high (e.g. relationships of CRT/BBS with ICAR and numeracy). These high correlations between cognitive abilities and CRT/BBS are not surprising as similar correlations are often reported in the literature (e.g., Blacksmith, Yang, Behrend and Ruark 2019; Toplak, West & Stanovich, 2011; Thomson & Oppenheimer, 2016). However, what is interesting are moderate to high correlations between our individual difference variables and success on CRT/BBS in the fast condition. This means that cognitive abilities and to a degree thinking dispositions are important not only in detecting the conflict and correcting erroneous intuitive responses, but also in generating correct intuitive responses. Third, cognitive abilities and thinking dispositions were also to some degree predictive of confidence in responses and response times. However, there were also some interesting insights here. For example, numeracy was significant predictor of confidence in CRT responses in fast condition, but not of confidence in BBS fast responses. This possibly reflects the importance of numeracy for strong CRT logical intuitions, but not so much for strong BBS logical intuitions. Finally, smarter and more numerate participants on average had the tendency of taking more time when responding in the slow condition, and this was more pronounced when solving BBS tasks.

In a bid to answer our main research questions, before repeating analyses that we did in Study 1, we first decided to replicate the analysis reported by Raoelison et al. (2020). They correlated cognitive abilities with proportions of “11”, “01” and “00” responses at the participant level (i.e., for each participant the number of his/her responses in each category was divided by the total number of his/her responses). We followed the same approach here. Therefore, in the Table 8 we are showing the correlations between our focal variables and the proportion of “11”, “01” and “00” responses.

Table 8. Correlations among the focal variables and proportions of response categories

	ICAR	NUM	AOT	NFC	MAT	CRT f. c.	CRT s. c.	CRT s. t.	BBS f. c.	BBS s. c.	BBS s. t.	BBS 00	BBS 01	BBS 11
CRT 00	-.53**	-.57**	-.07	-.21	-.45**	-.09	-.18	-.23*	.06	-.05	-.35**	.44**	-.13	-.40**
CRT 01	.28*	.08	.02	-.09	.25*	-.28*	.00	.49**	-.17	-.11	.30**	-.21	.07	.18
CRT 11	.38**	.56**	.06	.31**	.31**	.34**	.22	-.16	.12	.19	.13	-.31**	.05	.30**
BBS 00	-.38**	-.48**	-.32**	-.13	-.40**	.09	.11	-.19	.23*	.08	-.29**		-.37**	-.86**
BBS 01	-.07	.17	-.12	-.17	.03	-.19	-.24*	.04	-.39**	-.23*	.40**			-.15
BBS 11	.44**	.42**	.41**	.23*	.41**	.00	.02	.18	-.03	.04	.09			

Note. CRT 00 = Proportion of cognitive reflection “00” responses; CRT 01 = Proportion of cognitive reflection “01” responses; CRT 11 = Proportion of cognitive reflection “11” responses; BBS 00 = Proportion of belief bias syllogisms “00” responses; BBS 01 = Proportion of belief bias syllogisms “01” responses; BBS 11 = Proportion of belief bias syllogisms “11” responses; ICAR = International cognitive ability resource; NUM = Numeracy; AOT = Actively open-minded thinking; NFC = Need for cognition; CRT c. f. = Average confidence in responses on cognitive reflection tasks in the fast-responding situation; CRT c. s. = Average confidence in responses on cognitive reflection tasks in the slow-responding situation; CRT t. s. = Average response time on cognitive reflection tasks in the slow-responding situation; BBS c. f. = Average confidence in responses on belief bias syllogisms in the fast-responding situation; BBS c. s. = Average confidence in responses on belief bias syllogisms in the slow-responding situation; BBS t. s. = Average response time on belief bias syllogisms in the slow-responding situation.

Table 8 reveals what the Table 7 hinted at: cognitive abilities, knowledge and thinking dispositions are primarily responsible for forming strong logical intuitions that allow people to respond quickly and intuitively correctly on BBS and CRT tasks. Of course, in addition to this, they were also highly predictive of serious mindware deficiencies reflected in “00” responses, with thinking dispositions playing somewhat smaller role here. This seems logical to us: without sufficient degree of cognitive abilities and knowledge, no amount of disposition to think hard and carefully will be enough to come up with correct response to these tasks. Another interesting thing to notice is that the confidence in fast responses was positively correlated with the proportion of “11” responses and negatively with the proportion of “01” responses both for CRT and BBS tasks. This means that participants with more “11” responses were more confident in their initial responses, indicating that they experienced lower conflict between logical and erroneous intuition. Conversely, lower confidence in initial responses predicted probability of correcting erroneous intuition, indicating a conflict detection in “01” responses. This was also accompanied by longer response times meaning that the participants who detected the conflict and corrected their erroneous initial response took more time to think about the task and respond to it. Finally, it was interesting to see that there exists a moderate correlation between proportion of “00” and “11” responses across the two tasks. Participants with more “11” responses on CRT tasks also tended to have more “11” responses on BBS while those with more “00” CRT responses tended to also have more “00” BBS responses. Interestingly, there was no correlation in proportion of “01” responses between the tasks.

Finally, we conducted our main analyses to investigate the differences in abilities, dispositions and knowledge that underpin the three response types, “11”, “01” and “00”. The two tasks somewhat differed in the frequency of each category. For CRT, there were 189 “11” trials, 145 “01” trials and 159 “00” trials. For BBS, there were 302 “11” trials, 56 “01” trials and 171 “00” trials. Therefore, while 43% of the CRT correct trials were answered through deliberation (57% correct responses were given from the start, intuitively), only 16% of the BBS correct trial were given after deliberation. As in the Study 1, we again calculated one-way ANOVA for each of our dependent variables with response type as fixed factor and item as random factor. For CRT responses, ANOVAs were significant for every dependent variables except the AOT for which it was non-significant: ICAR (F (2, 20684) = 66.37, $p <$ .001, partial $\eta 2$ = .87), numeracy (F (2, 21485) = 85.99, $p < .001$, partial $\eta 2$ = .89), NFC (F (2, 15786) = 9.28, $p = .002$, partial $\eta 2$ = .54) and matura score (F (2, 15385) = 16.39, $p < .001$, partial $\eta 2$ = .68). General trend was that intuitive correct responses (“11”) were generally associated with highest intelligence, numeracy, NFC and mathematical knowledge, i.e. matura score, followed by “01” responses and lastly by “00” responses. However, not all the differences between the categories were significant. For example, “11” and “01” responses significantly differed only on numeracy ($t = 4.68$, $p < .001$, $d = .52$) and NFC ($t = 2.76$, $p = .006$, $d = .31$), but not on ICAR, matura score or AOT. The differences between the “01” and “00” categories were significant for ICAR ($t = 6.46$, $p < .001$, $d =$ .74), numeracy ($t = 4.97$, $p < .001$, $d = .55$) and matura score ($t = 4.66$, $p < .001$, $d = .55$), but not for NFC and AOT. The effects for significant ANOVAs are shown in the Figure 4.

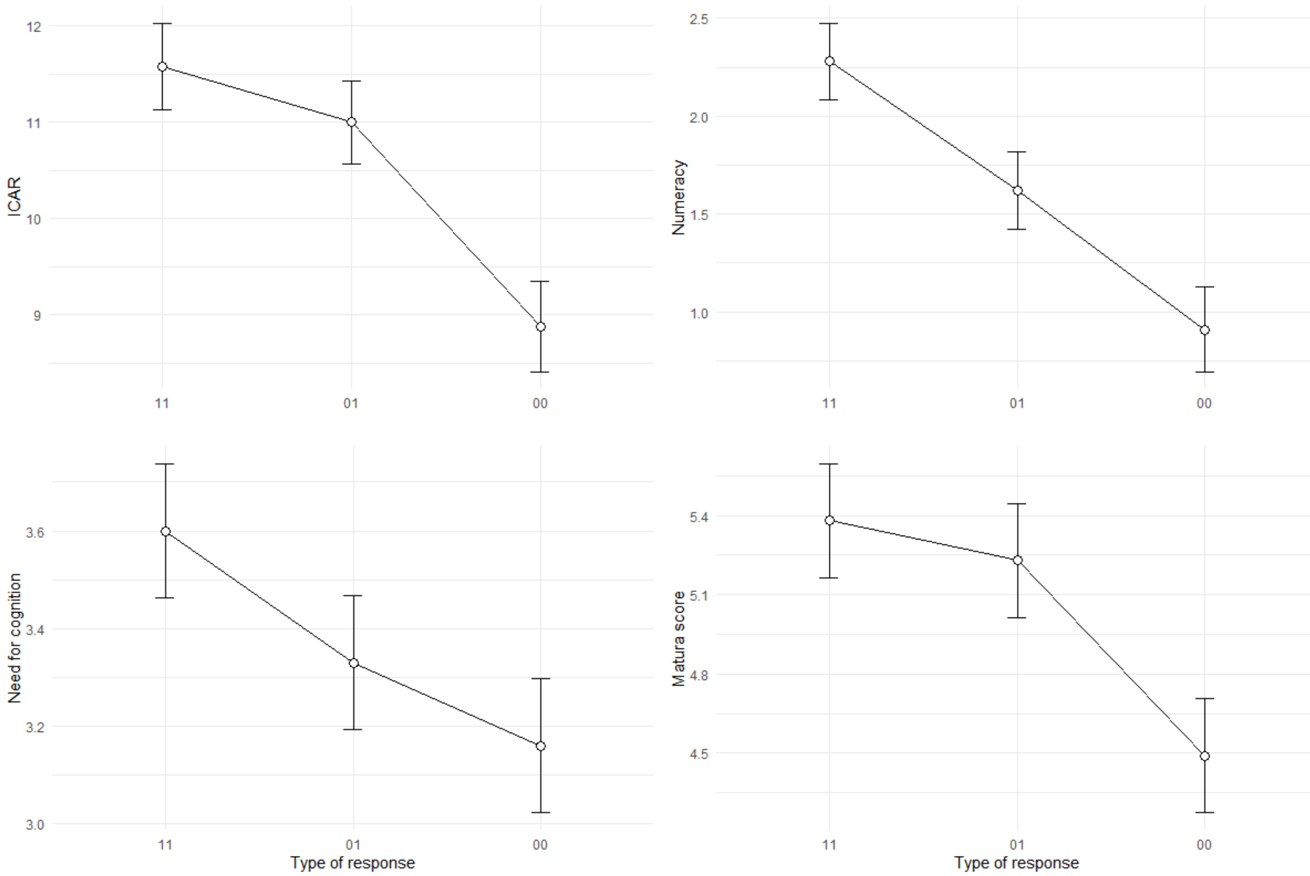

Figure 4. Significant differences on ICAR, numeracy, need for cognition and matura score between different response types for CRT tasks

For BBS responses, ANOVAs were significant for every dependent variable: ICAR (*F* (2, 39685) = 30.39, *p* < .001, partial *η2* = .61), numeracy (*F* (2, 33938) = 26.40, *p* < .001, partial *η2* = .61), AOT (*F* (2, 18671) = 18.51, *p* < .001, partial *η2* = .67), NFC (*F* (2, 59674) = 10.00, *p* < .001, partial *η2* = .25) and matura score (*F* (2, 38241) = 10.90, *p* < .001, partial *η2* = .36). "11" and "01" responses significantly differed on ICAR (*t* = 3.32, *p* = .001, *d* = .48), AOT (*t* = 2.73, *p* = .007, *d* = .40), NFC (*t* = 2.38, *p* = .017, *d* = .35) and matura score (*t* = 2.11, *p* = .036, *d* = .31), but not on numeracy. "00" and "01" responses differed on numeracy (*t* = 3.34, *p* = .001, *d* = .52) and AOT (*t* = 2.61, *p* = .010, *d* = .40), but not for ICAR. NFC and matura score. These effects are shown in the Figure 5.

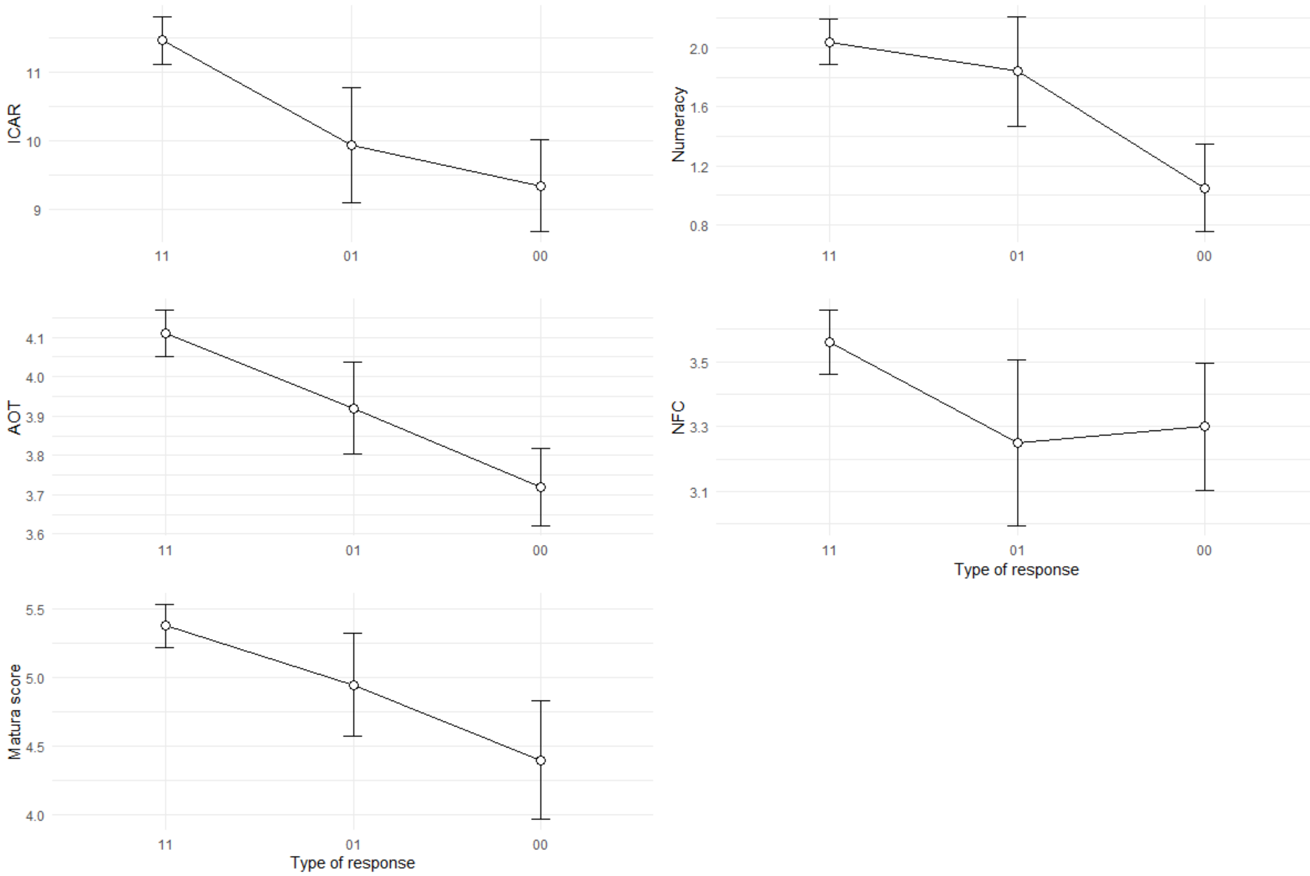

Figure 5. Significant differences on ICAR, numeracy, actively open-minded thinking, need for cognition and matura score between different response types for BBS tasks

In addition to these analyses, we conducted two more ANOVAs for each type of reasoning task to investigate how initial confidences (in the fast condition) and final response times (in the slow condition) differed across the three types of responses as these variables are indicative of conflict detection and deliberate correction of erroneous intuitions. For CRT responses, both ANOVAs were significant: for initial confidence ratings (F (2, 13588) = 23.62, p < .001, partial $\eta 2$ = .77) and for final response times (F (2, 13040) = 9.49, p = .003, partial $\eta 2$ = .59). For BBS responses, both ANOVAs were also significant: for initial confidence ratings (F (2, 17363) = 17.06, p < .001, partial $\eta 2$ = .66) and for final response times (F (2, 17221) = 10.53, p = .001, partial $\eta 2$ = .55). These effects are shown in the Figure 6. As can be seen from the Figure 6, the pattern of confidence and response time differences is similar for both tasks. Specifically, responses where participants managed to correct initially incorrect responses were related to lowest initial confidence and highest final response time, indicating that initial skepticism in one's response, possibly due to high conflict between the intuitions, predicted taking more time in the slow condition to correct the erroneous intuition and calculate the right response. On the other hand, responses where participants did not manage to respond correctly even after deliberation almost mimic the responses where participants gave correct response from the start. This indicates that in “00” responses participants had very little idea or feeling that something was wrong and that they should slow down and think about the problem more carefully. Therefore, it is not that these participants tried but failed to come up with the right response, it seems that they did not even try because they did not feel that they needed to. This is indicative of underdeveloped mindware and weak correct, logical intuition. Conversely, this pattern of responding (high initial confidence, low final response time) in “11” responses is indicative of highly developed mindware and very strong logical intuitions. Participants who responded in this way either did not bother much to carefully check their responses in slow condition as they knew they were right from the start or their high abilities and knowledge allowed them to run appropriate calculations and verify that they are right quickly, much quicker than participants with “01” responses could.

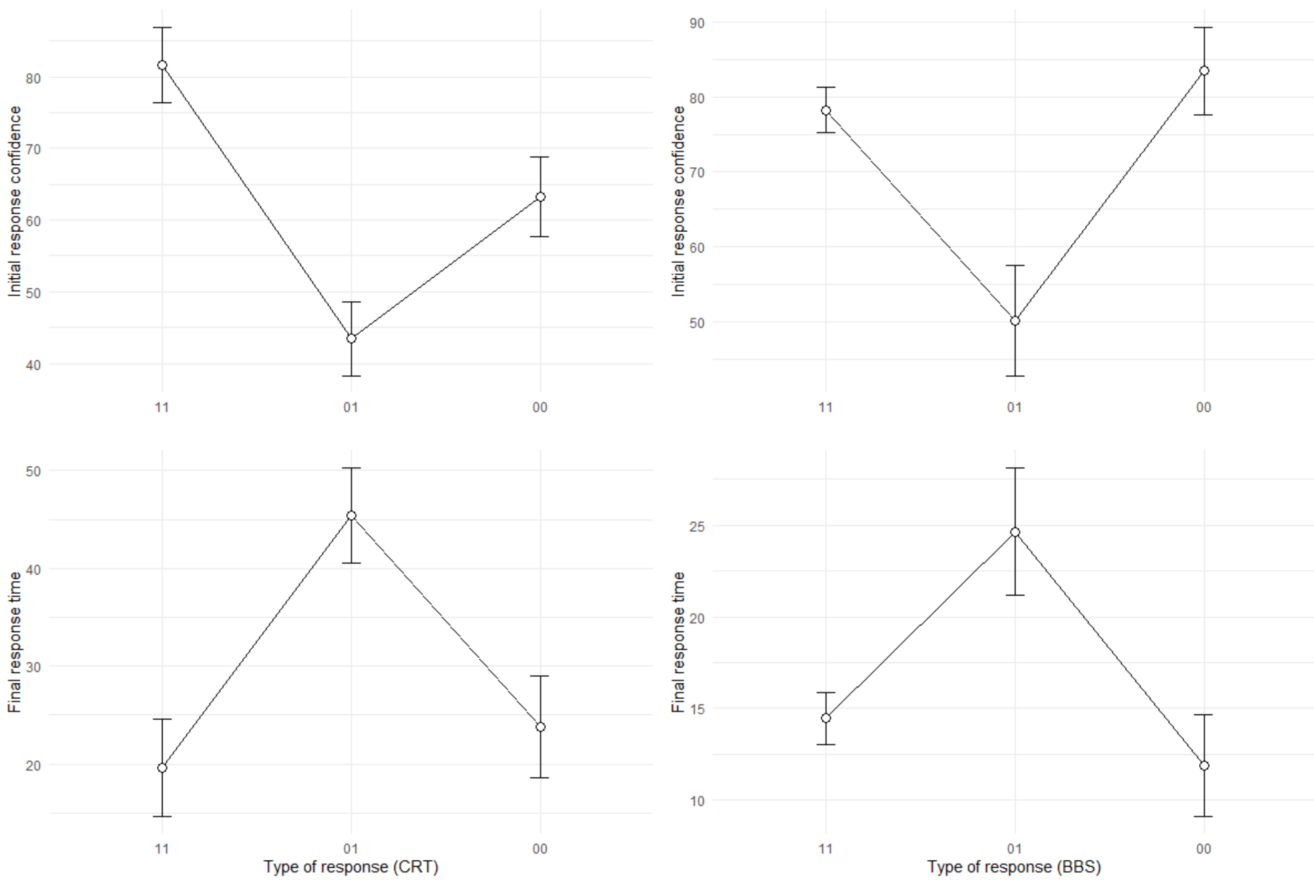

Figure 6. Average confidences in responses in the fast condition and average response times in the slow conditions for three different response types and the two reasoning tasks

3.3. Study 2 discussion

The two-response study showed that substantial differences in cognitive abilities, thinking dispositions and math knowledge underpin different types of responses on the two reasoning tasks. What is interesting is that these psychological traits not only differentiate between correct and incorrect responses, but also between different types of correct responses. Specifically, correct intuitive responses ("11") on CRT items were given by responders that were substantially more numerate and predisposed towards analytical thinking than those that gave deliberate correct responses. As we already noted, this suggests that the numeracy is one of the crucial ingredients of strong mindware relevant for CRT tasks, but also that disposition towards analytical thinking might be one of the crucial dispositions that help in development of such mindware. For BBS tasks, these two types of correct responses did not differ in numeracy which makes sense as BBS tasks do not require math knowledge. However, cognitive abilities and thinking dispositions again substantially differed between participants with "11" and "01" responses. Thus, although we did not capture specific knowledge and skills (i.e. mindware) relevant for BBS tasks in our studies, our findings suggests that high cognitive abilities and dispositions towards analytical thinking (i.e., need for cognition), as well as towards questioning our initial positions and seeking for alternative evidence and point of views (as indicated by AOT score), help in development of such mindware. How these results overlap with the results of the Study 1 and what are their implications for the role of abilities and dispositions in reasoning tasks, as well as for the validity of these reasoning tasks, will be discussed next.

4. General discussion

Across two studies we examined the differences in cognitive abilities, numeracy, math skills and thinking dispositions (actively open-minded thinking and need for cognition) associated with different ways of solving two types of reasoning tasks, cognitive reflection tasks and belief-bias syllogisms. In Study 1, based on the accuracy of responses and indicators of conflict detection, we classified responses in four categories (correct non-detections, correct detections, incorrect non-detections and incorrect detections) and three categories in Study 2 (correct intuitive responses, correct deliberate responses and incorrect responses).

Our two studies showed certain degree of overlap in their conclusions, but there were also some differences. We will try to explain both. Notably, Study 2 replicated the results of Study 1 regarding the importance of numeracy for CRT tasks. Numeracy was the key individual difference that differentiated between the types of responses on CRT tasks in both studies, not only between correct and incorrect responses, but also between the intuitive and deliberate correct responses. However, this was not the case for BBS tasks where it did not differ between intuitive and deliberate correct responses. This points to the conclusion that numeracy as we measured it is particularly indicative of the quality of mindware for CRT tasks. Not only does it capture cognitive abilities and dispositions important for success on these tasks, but it also assesses relevant math knowledge and experience indicative of highly developed mindware (Cokeley et al., 2012; Erceg et al., 2020; Skagerlund, Lind, Strömbäck, Tinghög, & Västfjäll, 2018; Sobkow, Olszewska, & Traczyk, 2020). As Ghazal, Cokely and Garcia-Retamero (2014) noted, numeracy is a potent predictor because it simultaneously assesses important metacognitive skills and mathematical competency. These results also work well with Peters et al. (2006) findings that highly numerate people had more clear feelings about what response option was correct on a ratio-bias task, a task that assess judgments of probabilities. Thus, people that are highly numerate seem to be more comfortable with numbers and to literary have “feelings” for numbers that might allow them to intuitively perceive the degree of rightness of response in tasks that depend on the math knowledge. Therefore, they can tell the right response from the wrong, even if they are not able to explain their decision without more careful deliberation (Bago & De Neys, 2019). As numerical/math knowledge is not particularly important for BBS tasks, numeracy was not indicative of highly developed mindware that allows for instant/intuitive correct responding, but given that it also captures cognitive abilities and dispositions relevant for success on BBS tasks, it was still able to differentiate between generally correct and incorrect responses.

The results are also in line with Reyna and colleagues (Reyna, Nelson, Han & Dieckmann, 2009; Reyna, Rahimi-Golkhandan, Garavito & Helm, 2017) fuzzy-trace theory that distinguishes between verbatim and gist representations of information. Verbatim representations of information are literally similar to information as presented, while gist representations of information refer to deriving the essential meaning of that same information (Reyna et al., 2017). Research has shown that people encode verbatim representations as well as multiple gist representations of the same information, with the gist-based intuition, not the verbatim representations, being an advanced model of reasoning (Reyna et al., 2009). This gist-based intuition is developed over time by processing information in a meaningful way. These meaningful insights shape gist-representations and enable transfer of knowledge to similar, but new stimuli. Therefore, as people gain experience at specific tasks, they tend to rely more on gist rather than verbatim representations, and these gist representations often result in better judgments and decisions (Reyna et al., 2017). We, of course, cannot say much about underlying representations of CRT and BBS tasks given our methodological approach, but this is something that would merit future research.

Regarding the BBS tasks, there are substantial differences between the conclusions of our Study 1 and Study 2. While in Study 1 neither of the individual differences we captured differed between correct detection and correct non-detection responses (i.e. intuitive correct and deliberate correct responses), in Study 2 all individual difference measures but numeracy differed between these types of responses. As we said previously, we believe that this means that cognitive abilities and thinking dispositions that we measured in this study are important for acquisition of adequate mindware for BBS tasks. Thus, we did not capture the relevant mindware (as we perhaps did for CRT by our numeracy measure), but we did capture traits conductive of its acquisition. We will argue later that this has substantial implications for the role of cognitive abilities and thinking dispositions in the success on popular reasoning tasks. Finally, we believe that the discrepancies between the two studies highlight some of the shortcomings of Study 1. As we argued earlier, our classification of responses in Study 1 was far from perfect, resulting probably in blurred and decreased potential differences between the responses, which is especially the case for the BBS tasks where we relied only on a single detection indicator.

Our study offers additional evidence for reconceptualization of the role of cognitive abilities and thinking dispositions in success on judgment and decision-making tasks. As Raoelison et al. (2020) note, classical “smart deliberator” view posits that those smarter and prone to analytical thinking are better at CRT, BBS and other famous reasoning tasks because they are a) more careful and tend to think deeper about the problems which allows them to detect that they are being lured into incorrect response, and b) smarter, which allows them to easily arrive at the right response once they have detected these lures. This is the view also favored by the tripartite theory (Stanovich et al., 2016) where both reflective mind (i.e. thinking dispositions) and algorithmic mind (i.e. cognitive capacities) are at work when individual correctly solves reasoning tasks.

Results from several recent studies (e.g. Raoelison et al., 2020; Schubert et al., 2021; Thompson et al., 2018), as well as ours, shed additional light on the role of abilities and dispositions and question this "smart deliberator" view. Specifically, from the perspective of the hybrid, logical intuition model, the main role of abilities and dispositions is in acquiring the relevant and quality mindware for solving these reasoning tasks. Thus, instead of helping people to recognize they are lured into wrong responses and to calculate/identify the right response, these traits act as building blocks of relevant mindware that is acquired through repeated exercise and exposure. Dispositions towards analytical thinking (e.g. need for cognition, actively open-minded thinking) ensure that a person enjoys engaging with tasks that require relevant knowledge and/or hard thinking over prolonged period of time and cognitive abilities ensure that he/she is able to extract relevant and transferrable knowledge and meaning from these tasks. Therefore, over the time, people that are higher on thinking dispositions and cognitive abilities manage to develop adequate, relevant, and strong mindware and intuitions, for these types of tasks, allowing them to rely more on their feelings and intuitions than on deliberate processing of specific information. This, and not careful thinking and deliberate calculation, is what drives the correlation between cognitive abilities/thinking dispositions and success on these reasoning tasks.

However, it is possible to go a step further here and argue that this relationship also depends on the opportunity to engage with such tasks. For example, educational system provides ample opportunity for person to engage with various math tasks and even basic logic. Thus, if one has dispositions to engage with these tasks on a deeper level and capacity to draw adequate lessons from tasks, the prerequisites for developing strong mindware over time are set. However, when such opportunity is not readily available, then the repeated engagement is much harder and much more dependent on the individual. This latter situation is less conductive of development of sufficient mindware and strong logical intuitions. A comparison between recent findings based on think-aloud protocols of classic numerical CRT and verbal CRT support this view. Szaszi et al. (2017) showed that, when solving numerical CRT, majority of responders who responded correctly immediately gave correct response, or at least started with a line of reasoning that leads to correct response, without mentioning the incorrect intuitive response. Conversely, using think-aloud protocol in their study on verbal CRT, Byrd, Joseph, Gongora and Sirota (2021) found that majority of the correct responses was not given intuitively, but instead involved reflection. An example of the verbal CRT item is “How many of each animal did Moses put on the ark?” (Moses did not put two animals on the ark, it was Noah; Sirota, Dewberry, Juanchich, Valuš & Marshall, 2021). Following our previous explanation, we would argue that this discrepancy can be explained by differences in opportunity to engage in these two types of tasks and, thus, differences in mindware instantiation. Unlike CRT and BBS tasks for which the relevant skills can be obtained throughout schooling, experience and skills needed for verbal CRT are not obtained through formal schooling (but perhaps through being fooled multiple times on the school playground or something similar). Therefore, many people can have strong intuitions for CRT, BBS, ratio-bias or base-rate neglect tasks, but not for verbal CRT tasks (and perhaps for other stumpers and riddles).

Related to this, our final point is that our results have also implications for validity of (at least) CRT and BBS tasks as measures of reflection, analytical thinking engagement or miserly processing (e.g. Böckenholt, 2012; Frederick, 2005; Pennycook, Cheyne, Koehler & Fugelsang, 2016; Pennycook, Fugelsang & Koehler, 2015; Pennycook & Ross, 2016; Toplak et al., 2014). Given plethora of findings from the two-response paradigm that show that, when solved correctly, CRT, BBS and some other tasks are solved in the majority of cases intuitively correctly, without the need to engage in deliberate thinking, it is questionable to what degree a correct response on such tasks is indicative of reflective or analytical thinking. In fact, it seems that only minority of people respond to these tasks through careful deliberation and engagement in analytical thinking. One obvious repercussion of this is that these tasks are not particularly good measures of analytical thinking as they are mostly solved intuitively.

However, given our results, another possibility is that these tasks are still able to capture disposition towards analytical thinking, only not through the mechanisms previously thought. As explained earlier, we believe that the correlations between thinking dispositions and reasoning tasks are not the result of high disposition people being more likely to detect and override the conflict, but the result of thinking dispositions being conductive of more developed mindware over time. Therefore, even though these tasks are mostly solved by relying on intuition, they are still able to capture propensity to generally be careful, more deliberate, and analytic thinker. Some other tasks (for example, abstract reasoning tasks with which a person has little experience or had little opportunity to engage with) might be better indicators of analytical and reflective thinking in the sense that they actually require deeper engagement and propensity towards analytical thinking to be solved correctly. One last implication of this is that, for the task to be a good indicator of reflective/analytical thinking, the lures are probably not crucial. This is exactly what several recent findings showed (e.g. Attali & Bar-Hillel, 2020; Baron et al., 2015; Erceg, Galić & Ružojčić, 2020). Basically, to be solved correctly every cognitive task with which one does not have ample experience or skills will draw both on cognitive capacities and on thinking dispositions to be careful and reflective. It is impossible or at least very hard to develop a task that would be free from the effects of thinking dispositions. This is also at the core of Baron (1985) definition of intelligence as something that includes capacities (more stable and less prone to change) and dispositions (more prone to change and teaching attempts).

5. Conclusion

In sum, it seems that different problem solvers solve reasoning problems in qualitatively substantially different ways and that the differences in intelligence, numeracy, math skills and thinking dispositions underpin these different approaches. Those lowest on these attributes have underdeveloped mindware and weak logical intuitions, sometimes not even strong enough to make them question their first response. The higher these attributes are, the better the mindware and stronger the correct intuitions, resulting in first detecting the conflict and eventually even overturning the initial wrong response. Finally, among those highest on cognitive abilities, numeracy, math skills and actively open-minded thinking, mindware is so developed and correct intuitions are so strong that a correct response is given instantly, with very little conflict detection. This sequence is in line with the logical intuitions model and mindware instantiation continuum (Stanovich, 2018; Purcell et al., 2020), but does not fit well with the classic dual-processes narrative that posits that correct responses must come from deliberate and time-consuming Type 2 processing. These results have implications both for the role of cognitive abilities and thinking dispositions in task performance and for the validity of CRT and BBS as measures of analytical thinking or reflection. Smarter and those more prone towards analytical thinking are good CRT/BBS solvers not because these traits allow them to detect the conflict and correct the erroneous intuition, but because they are conductive of attaining better mindware and stronger logical intuitions. As these intuitions enable correct intuitive responding in most cases, CRT and BBS are hardly good measures of reflection/analytical thinking.

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Appendix

Study 1 items

CRT items

1. A bat and a ball together cost 110 kunas. The bat costs 100 kunas more than the ball. How much does the ball cost?
2. If it takes 5 machines 5 minutes to make 5 widgets, how long would it take 100 machines to make 100 widgets?

3. In a lake, there is a patch of lily pads. Every day, the patch doubles in size. If it takes 48 days for the patch to cover the entire lake, how long would it take for the patch to cover half the lake?
4. Simon decided to invest $8,000 in the stock market one day early in 2008. Six months after he invested, on July 17, the stocks he had purchased were down 50%. Fortunately for Simon, from July 17 to October 17, the stocks he had purchased went up 75%. At this point, Simon has: a. broken even in the stock market, b. is ahead of where he began, c. has lost money.
5. A farmer had 15 sheep and all but 8 died. How many are left?

CRT control items

1. The magazine and banana cost 29 kunas. The magazine costs 20 kunas. How much does a banana cost?
2. If it takes 1 machine 5 minutes to make 5 widgets, how long would it take 1 machine to make 100 widgets?
3. In a lake, there is a patch of lily pads. Every day, the patch grows for 10 m2. If it takes 30 days for the patch to cover the 400 m2 of the lake, how long would it take for the patch to cover 390 m2 of the lake?
4. On Monday, the air temperature was 22 °C. Two days later, temperatures dropped by 50%. Fortunately, by Saturday the temperature had risen again by 125%. Compared to Monday, on Saturday it was: a. Equally warm; b. Warmer; c. Colder.
5. A man had 15 apples, but he decided to share 8. How many apples are left?

BBS items

1. Premise 1: All unemployed people are poor. Premise 2: Todorić* is not unemployed. Conclusion: Todorić* is not poor.
2. Premise 1: All flowers have petals. Premise 2: Roses have petals. Conclusion: Roses are flowers.
3. Premise 1: All Eastern countries are communist. Premise 2: Canada is not an Eastern country. Conclusion: Canada is not communist.
4. Premise 1: All things that have a motor need oil. Premise 2: Automobiles need oil. Conclusion: Automobiles have motors

Study 2 items

CRT items

1. A bat and a ball together cost 110 kunas. The bat costs 100 kunas more than the ball. How much does the ball cost?
2. If it takes 5 machines 5 minutes to make 5 widgets, how long would it take 100 machines to make 100 widgets?

3. In a lake, there is a patch of lily pads. Every day, the patch doubles in size. If it takes 48 days for the patch to cover the entire lake, how long would it take for the patch to cover half the lake?
4. A farmer had 15 sheep and all but 8 died. How many are left?
5. A square shaped garage roof with 6 meters long edge is covered with 100 tiles. How many tiles of the same size are covering a neighboring roof, which is also square shaped, but with a 3 meters long edge?
6. If you were running a race, and you passed the person in 2nd place, what place would you be in now?
7. Jerry received both the 15th highest and the 15th lowest mark in the class. How many students are in the class?

BBS items

1. Premise 1: All unemployed people are poor. Premise 2: Todorić* is not unemployed. Conclusion: Todorić* is not poor.
2. Premise 1: All things that are smoked are good for the health. Premise 2: Cigarettes are smoked. Conclusion: Cigarettes are good for the health.
3. Premise 1: All flowers have petals. Premise 2: Roses have petals. Conclusion: Roses are flowers.
4. Premise 1: All animals love water. Premise 2: Cats do not like water. Conclusion: Cats are not animals.
5. Premise 1: All Eastern countries are communist. Premise 2: Canada is not an Eastern country. Conclusion: Canada is not communist.
6. Premise 1: All mammals walk. Premise 2: Whales are mammals. Conclusion: Whales walk.
7. Premise 1: All things that have a motor need oil. Premise 2: Automobiles need oil. Conclusion: Automobiles have motors

* Todorić is a well-known Croatian rich businessman