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Eye Movements, Pupil Dilation, and Conflict Detection in Reasoning: Exploring the Evidence for Intuitive Logic

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Abstract

A controversial claim in recent dual process accounts of reasoning is that intuitive processes not only lead to bias but are also sensitive to the logical status of an argument. The intuitive logic hypothesis draws upon evidence that reasoners take longer and are less confident on belief–logic conflict problems, irrespective of whether they give the correct logical response. In this paper, we examine conflict detection under conditions in which participants are asked to either judge the logical validity or believability of a presented conclusion, accompanied by measures of eye movement and pupil dilation. The findings show an effect of conflict, under both types of instruction, on accuracy, latency, gaze shifts, and pupil dilation. Importantly, these effects extend to conflict trials in which participants give a belief-based response (incorrectly under logic instructions or correctly under belief instructions) demonstrating both behavioral and physiological evidence in support of the logical intuition hypothesis.

Keywords: Conflict detection; Reasoning; Eye tracking; Pupil dilation; Dual processes; Intuitive logic

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1. Introduction

The idea that many of the judgments that we make are intuitive has a long history in psychology (e.g., Evans, 2008; Gilovich, Griffin, & Kahneman, 2002). Such intuitive judgments are claimed to play a role in social impressions (Lieberman, 2000), stereotypes (Greenwald & Banaji, 1995), learning (Reber, 1989), memory (Morwedge & Kahneman, 2010), and judgment and decision making (Kahneman & Frederick, 2005), together with many other cognitive, social, and perceptual processes. A common assumption underlying models of intuition is that judgments come to mind rapidly and automatically, and people are unaware of the origins of these thoughts (e.g., De Neys, 2012; Stanovich, 2018). In reasoning and decision-making research, it has been consistently shown that our intuitions can lead to systematic errors and biases in judgment. Such intuitions are automatic, come to mind effortlessly, and are often based upon simplifying heuristics that draw upon cues that do not have explicit justification or validity in the context of the task at hand (Kahneman, 2011). For example, in reasoning, it is well known that the believability of a conclusion can influence its acceptance rate independently of its actual logical status (Evans, Barston, & Pollard, 1983). Considering this, a crucial task for cognitive science is to identify those conditions under which people can resist the influence of heuristics and instead draw upon logical principles to guide their reasoning.

The belief bias effect in reasoning is a foundational effect that has underpinned the development of traditional dual process accounts of reasoning (Evans, 2003; Evans & Stanovich, 2013; Kahneman, 2011; Stanovich & West, 2000). According to these accounts, belief-based responses are generated quickly, drawing upon intuitive "Type 1" processes, and when in conflict with a logical response, can lead to error unless reasoners have the capacity and motivation to apply logical rules through deliberative "Type 2" processing (Evans & Curtis-Holmes, 2005). Belief bias is assumed to be the result of human miserliness, or the inclination to restrict cognitive effort, rather than to engage in effortful logical reasoning (Stanovich, 2018; Toplak, West, & Stanovich, 2014).

Recently, researchers have challenged this view, claiming that reasoning based upon logical principles can, in fact, occur at a fast and intuitive level of processing. For example, experiments aimed at knocking out Type 2 processing with time constraints (Pennycook, Trippas, Handley, & Thompson, 2014; Thompson & Johnson, 2014) cognitive load (Franssens & De Neys, 2009; Johnson, Tubau, & De Neys, 2016) or both (Bago & De Neys, 2017) have shown that sensitivity to conflict and correct normative responses can occur at the intuitive stage of processing (Burič & Konrádová 2021; Burič & Šrol, 2020). Dual process 2.0 models (De Neys, 2018; De Neys & Pennycook, 2019) claim that belief-based and logic-based responses are activated intuitively and in parallel, leading to the detection of conflict that may or may not be resolved through the intervention of Type 2 deliberative processes (e.g., Bago & De Neys, 2017; De Neys, 2012; Handley & Trippas, 2015). This claim is supported by evidence that reasoning under conflict tends to take longer and causes a decrease in confidence ratings (De Neys & Glumicic, 2008; De Neys, Cromheeke, & Osman, 2011) and feelings of rightness (Thompson, Turner, J., & Pennycook, 2011) and increases in feelings of error (Gangemi, Bourgeois-Gironde, & Mancini, 2015). These effects hold even when reasoners give a biased belief-based response, suggesting that the logical response is activated, irrespective of whether this response is given.

The evidence for "logical intuition," is not confined to studies in which participants are instructed to provide a logical response. In recent research, reasoners have been asked to judge how much they "like" a presented statement that might or might not logically follow from the statements presented immediately preceding it (Morsanyi & Handley, 2012; Trippas, Handley, Verde, & Morsanyi, 2016). In other studies, participants may be asked to rate the brightness (contrast) of the conclusion (Ghasemi, Handley, & Howarth, 2022a) or to generate random responses to a series of logical problems (Howarth, Handley, & Polito, 2022). Logical validity has been shown to systematically influence liking and brightness ratings and influence random responses.

Despite the diverse evidence supporting the "logical intuition" hypothesis, researchers have recently challenged the claim that the effects of logic arise from automatic intuitive processing. For example, research has shown that those higher in cognitive ability produce stronger logic effects in their liking judgments (Ghasemi et al., 2022a; Hayes, Wei, Dunn, & Stephens, 2020) and that the logic effect is moderated by working memory load (Hayes et al., 2020). More recently, Meyer-Grant and colleagues showed that the liking logic effect is stronger for participants who self-report utilizing logic in their judgments (Meyer-Grant et al., 2022). This suggests that logic effects on these tasks arise because the requirements of the task are unclear, and participants are hence utilizing logical structure as a cue for responding. Similarly, with regard to the brightness judgment task, logic effects only emerge when the brightness discrimination is difficult, and it has been argued that under such challenging judgment conditions, participants utilize the logic cue as a basis for responding (Hayes et al., 2022).

The claim that intuitive logic arises from deliberative processes is so far limited to the liking and brightness judgment tasks. However, it is possible that the conflict detection effects described earlier do not arise because the logical inference is activated automatically but instead because reasoners are engaged in deliberative reasoning. After all, a typical conflict reasoning paradigm involves explicitly instructing participants to reason logically and then evaluating the impact of belief–logic conflict on a range of behavioral measures such as accuracy, latency, and confidence. In this study, we utilize an instructional manipulation in which participants are instead presented with conflict problems and asked to either judge whether the conclusion is believable or whether it is logically valid. Previous studies utilizing this task have shown that belief–logic conflict interferes with both belief judgments and logic judgments (Handley, Newstead, & Trippas, 2011; Howarth, Handley, & Walsh, 2016, 2019; Trippas, Thompson, & Handley, 2017). This suggests that under the belief instruction condition, reasoners are automatically drawing the logical inference, and this is then interfering with their ability to evaluate the belief status of the conclusion. The current study uses pupil dilation and eye gaze measures to determine whether a conflict is detected, and hence go some way to determining whether intuitive logic effects reflect intuitive processing. Before outlining our study in more detail, we briefly review relevant literature on these eye movement measures.

The study of cognitive processes and pupillometry, dating as far back as the 1960s (Hess & Polt, 1964; Kahneman & Beatty, 1966), has shown that an increase in pupil diameter occurs in response to an increase in the demands of a task. Van der Wel and van Steenbergen's (2018) review of cognitive control tasks (updating, task switching, and inhibition) confirmed that pupil dilation can be used as an indirect index of [cognitive] effort. For example, pupil dilation is related to inhibitory control (Hershman, Henik, & Cohen, 2018), conflict monitoring (van Steenbergen & Band, 2013), and cognitive control (Cavanagh, Wiecki, Kochar, & Frank, 2014). While the aforementioned research focuses on explicit conflict, other research highlights the impact of implicit conflict on pupil dilation. For example, Laeng, Ørbo, Holmlund, and Miozzo (2011) showed that pupil size increases as demands increase using the Stroop task. They established pupillometry as a robust measure of implicit conflict between task-appropriate and automatic responses. They argued that changes in pupil diameter could be regarded as a valid substitute for traditional performance measures such as reaction times (RTs) and may even be used to identify effects that RTs are unable to distinguish. Relatedly, Kozunova et al. (2022) hypothesized that similar comparisons could be made with value-driven choice tasks, whereby the learned value of an advantageous choice can create an unconscious value-driven bias. Implicit conflict with this bias arises when a safe action is overruled by a risky exploratory decision, supported by increases in behavioral measures such as RTs and physiological measures such as pupil dilation.

Crucially, recent research has also revealed that pupil-linked arousal is positively related to uncertainty in serial choice tasks (Urai, Braun, & Donner, 2017) and negatively correlated with metacognitive confidence in a decision task (Lempert, Chen, & Fleming, 2015). Amid this resurgence of pupillometry techniques, reasoning research demonstrated that both (1) metacognitions like confidence and feelings of rightness (for a review, see Ackerman & Thompson, 2017) and (2) judgments of brightness varied as a function of belief–logic conflict (Ghasemi et al., 2022a; Trippas et al., 2016). Together these findings provide a strong rationale for expecting pupil dilation to vary as a function of belief–logic conflict.

In addition to pupil dilation, eye movements may also be sensitive to belief–logic conflict. Previous research has demonstrated that some forms of conflict during reasoning affects reasoner's eye movements; Ball (2014) found that participants took longer examining conflict problems even when they give belief-based responses in error (Ball, Phillips, Wade, & Quayle, 2006). Purcell, Wastell, Howarth, Roberts, and Sweller (2022) observed that participants made a greater number of eye movements on incorrect conflict responses, compared to control items. That is, even when participants' behavioral responses were in error, they showed intuitive sensitivity to the logical information. Moreover, recent studies reveal that eye movements are negatively related to judgments of confidence (Purcell et al., 2022) and positively related to the engagement of effortful thinking (Purcell, Wastell, & Sweller, 2022). The growing evidence suggesting that metacognitions and conflict have systematic impacts on eye movements is promising for the use of gaze-based indicators in determining the intuitive impacts of belief–logic conflict.

Given the relationships between conflict processing and both pupil dilation and gaze, we expected these physiological markers to be sensitive to the detection of conflict under logical instructions, where an effect of conflict arises from competing beliefs. Importantly, however, this study also addresses the more controversial claim that we should also observe physiological indications of conflict under belief instructions, where an effect of conflict arises because of the activation of a competing logical response. In summary, across both logic and belief instructions, we expected to find differences in these markers for problems in which logical structure and believability are aligned (no conflict) or misaligned (in conflict). Specifically, we predicted that:

Hyp. 1: Lower accuracy, increased response latency, increased pupil dilation, and a greater number of gaze movements would be observed on conflict compared to no-conflict problems across both logical and belief instructions.

In addition to our primary comparison of conflict and no-conflict problems, we also explored whether reasoners showed sensitivity to conflicting logic when they generated belief-based responses (either in error under logic instructions or correctly under belief instructions). This type of analysis has been used extensively in conflict detection studies to provide evidence that reasoners activate a conflicting logical inference even when they give a belief-based response in error (De Neys & Glumicic, 2008). If participants give a belief-based response on conflict problems under logical instructions in error, but the logical response is activated, we would expect this to be marked by increased latency, gaze shifts, and dilation, compared to non-conflict problems. By a similar rationale, if participants correctly give a belief-based response under belief instructions on conflict problems, if the competing logical response is activated, then they should show increased latency, gaze, and dilation, compared to trials in which the logical and belief-based responses are aligned. Following this argument, we also predicted:

Hyp. 2: Under belief instructions, participants will be slower, show a greater number of eye movements, and larger pupil dilation on correct conflict trials, compared to correct no-conflict trials.

Hyp. 3: Under logic instructions, participants will be slower, show a greater number of eye movements, and larger pupil dilation on incorrect conflict trials (i.e., belief-aligned responses with logically conflicting information), compared to correct no-conflict trials.

2. Method

2.1. Participants

Thirty-eight undergraduate psychology students participated in the experiment in exchange for course credit. Ages ranged from 18 to 36 ($M = 19.76$, $SD = 3.54$), with 27 participants identifying as female and 11 identifying as male. All participants had normal vision (i.e., no glasses or contact lenses).

2.2. Procedure

The chair and chinrest were adjusted to comfortable positions for the participant before commencing the experiment. After a nine-point eye-tracking calibration, participants were presented with instructions (see Supplementary Material) and four practice trials.

Experimental trials were presented in four blocks with a 3-min break between each block. A nine-point calibration was conducted before each block of trials, and a one-point calibration was conducted before each item. If a one-point calibration failed, a nine-point calibration was repeated.

At the start of each trial, a fixation cross appeared in the center of the screen for 3000 ms. After this, the major premise appeared for 3000 ms, followed by the minor premise for 3000 ms, and then the conclusion. After the conclusion was displayed for 3000 ms, it was joined by the two response options (valid/invalid or believable/unbelievable). The conclusion and response options remained on the screen until the participant made their response. This means that participants only received instruction on how to respond *after* being presented with the reasoning problem. At the end of the experiment, participants provided their age and gender.

2.3. Apparatus and materials

2.3.1. Reasoning task

Participants were presented with 96 reasoning problems in random order. Half the problems were conditional arguments and half were disjunctions. For each problem type, half were logically valid, and half were determinately invalid. For each level of validity, half the arguments had believable conclusions and half had unbelievable conclusions. Validity and believability were then crossed to determine the conflict status of the argument, such that valid and believable or invalid and unbelievable resulted in a non-conflict trial, whereas valid and unbelievable or invalid and believable resulted in a conflict trial. Finally, for each level of conflict, half the arguments were paired with the instruction to answer according to logical validity, and half were paired with the instruction to answer according to conclusion believability. The design was a 2 (belief vs. logic instructions) by 2 (conflict vs. no-conflict) by 2 (conditional vs. disjunctive problems) fully within-participants. Accuracy and response latencies were recorded for every trial (Table 1).

2.3.2. Eye and pupil tracking equipment

The reasoning task was built using Experiment Builder presentation software 1.10.165 (SR Research) and presented on a 24.5-inch LCD monitor (240 Hz, 1920 × 1080). Eye movements and pupil dilation were recorded monocularly (right eye) with a desk-mounted EyeLink 1000 tracker sampling at a rate of 1000 Hz (SR Research). A chinrest was used to stabilize head movements and maintain viewing distance of 800 mm. Responses were made by pressing the left (valid/believable) or right (invalid/unbelievable) key on a Cedrus box.

2.3.3. Eye and pupil tracking measures

Three areas of interest (AOIs) were created for the conclusion and response screen (see Fig. 1). As shown in Fig. 1, AOIs were created for (1) the conclusion presented in the center of the screen, (2) for the "left" option presented below the conclusion, equidistant from the center and the left edge of the screen, and (3) for the "right" option presented below the conclusion, equidistant from the center and the right edge of the screen. For our analysis,

Table 1
A sample of the no conflict and conflict arguments (Modus Ponens only) and the required responses under belief and logic instruction

No Conflict	Conflict
If the fire is burning then the room is hot The fire is burning Therefore, the room is hot Valid = Yes Believable = Yes	If the fire is burning then the room is cold The fire is burning Therefore, the room is hot Valid = No Believable = Yes
If the fire is burning then the room is hot The fire is burning Therefore, the room is cold Valid = No Believable = No	If the fire is burning then the room is cold The fire is burning Therefore, the room is cold Valid = Yes Believable = No

Note. For the full set of stimuli see the Supplementary Material.

Fig. 1. Participants were presented with each item gradually such that they saw a fixation cross, premise 1, premise 2, the conclusion, and finally the conclusion and response options. This figure represents the final stage of the item presentation with the conclusion and response items on the screen. Saccades were calculated as any eye movements between two of the areas of interest (AOIs) and pupil measures were taken while the participant was fixating within AOI 1.

Table 2
Means and standard errors, *M* (*SE*), for accuracy, latencies, gaze movements, and pupil dilation by conflict and instructions

Instructions	Conflict	Accuracy (%)	Dilation	Gaze Movements	Latency
Belief	Conflict	58.5 (4.4)	742.6 (7.9)	1.8 (0.1)	1244.7 (19.0)
	No Conflict	92.3 (1.1)	731.5 (7.8)	1.3 (0.1)	1051.7 (18.5)
Logic	Conflict	73.6 (3.7)	739.0 (7.9)	1.4 (0.1)	1078.5 (17.8)
	No Conflict	92.1 (1.2)	727.1 (7.6)	1.1 (0.04)	956.6 (16.8)

saccades were calculated as the number of eye movements that occurred between any two of the three AOIs while the conclusion and response options remained on screen (Purcell et al., 2022). A pupil measurement was recorded every 20 ms provided the participant was fixating within AOI 1 and the eye was not in saccade.[1] For our analysis, pupil dilation was calculated as the average dilation measurement from when the response options were presented until either a response was recorded or until 2000 ms after the response options were presented.

3. Results

3.1. Analysis plan

The following analyses are divided into three sections. In Section 1, we report the effects of our two key independent variables—conflict (conflict, no-conflict items) and instructions (belief, logic)—on our four dependent variables: accuracy, latency, gaze patterns, and pupil dilation.[2] In Sections 2 and 3, we report our secondary analyses that compare latencies, gaze, and pupil dilation on those conflict trials in which participants give a belief-based response, compared to no-conflict trials in which participants give a correct response. This allows us to determine whether reasoners are showing sensitivity to logical validity, even when they give a response that is consistent with their beliefs. All analyses for latency, gaze, and dilation used general linear mixed models,[3] and the analysis for accuracy used a generalized mixed model with a logit function.[4] Raw data and scripts for the analyses are stored on OSF: Physiological Markers & Logical Intuition

3.1.1. Section 1: Conflict and instructions

As Table 2 shows, accuracy was lower for conflict than no-conflict items. The model predicting accuracy showed a main effect of conflict (*Odds Ratio (OR)* = 0.11, 95% *Confidence Interval (CI)* [0.08, 0.14]; $Z = -16.63$, $p < .001$), no main effect of instructions (*OR* = 0.96, 95% *CI* [0.70, 1.32]; $Z = -0.25$, $p = .799$), and an interaction between conflict and instructions (*OR* = 2.31, 95% *CI* [1.59, 3.36], $Z = 4.38$, $p < .001$). Although accuracy was lower for conflict than no-conflict items, this effect was stronger under belief instructions (*OR* = 0.08, 95% *CI* [0.06, 0.11], $Z = -16.84$, $p < .001$) than logic instructions (*OR* = 0.21, 95% *CI* [0.16, 0.28], $Z = -10.76$, $p < .001$).

As Table 2 shows, latencies were greater for conflict than non-conflict items. The model predicting latency showed a main effect of conflict ($\beta = 0.33$, 95% *CI* [0.25, 0.40], $t(4121) = 8.71$, $p < .001$), a main effect of instructions ($\beta = -0.16$, 95% *CI* [−0.23, −0.09], $t(4121) = -4.26$, $p < .001$), and a significant interaction between conflict and instructions ($\beta = -0.12$, 95% *CI* [−0.23, −0.02], $t(4121) = -2.30$, $p = .022$). Although latencies were longer for conflict than no-conflict items, the effect of conflict was stronger under belief ($\beta = 0.32$, 95% *CI* [0.24, 0.39], $t(2060) = 8.48$, $p < .001$) than logic instructions ($\beta = 0.22$, 95% *CI* [0.14, 0.29], $t(2059) = 5.68$, $p < .001$).

As Table 2 shows, people made more gaze movements on conflict than no-conflict items. The model predicting gaze showed a main effect of conflict ($\beta = 0.27$, 95% *CI* [0.19, 0.35], $t(4121) = 6.76$, $p < .001$), a main effect of instructions ($\beta = -0.12$, 95% *CI* [−0.20, −0.04], $t(4121) = -3.07$, $p = .002$), and a significant interaction between conflict and instructions ($\beta = -0.11$, 95% *CI* [−0.23, −2.57e-03], $t(4121) = -2.01$, $p = .045$). Although there were more gaze movements made on conflict than no-conflict items, the effect of conflict was stronger for belief ($\beta = 0.27$, 95% *CI* [0.19, 0.35], $t(2108) = 6.88$, $p < .001$) than logic instructions ($\beta = 0.16$, 95% *CI* [0.08, 0.24], $t(2059) = 3.88$, $p < .001$).

As Table 2 shows, dilation was greater for conflict than no-conflict items. The model predicting dilation showed a main effect of conflict ($\beta = 0.04$, 95% *CI* [0.01, 0.07], $t(4020) = 2.66$, $p = .008$), no effect of instructions ($\beta = -0.02$, 95% *CI* [−0.05, 7.11e-03], $t(4020) = -1.50$, $p = .133$), and no interaction between conflict and instructions ($\beta = 6.11\text{e-}03$, 95% *CI* [−0.04, 0.05], $t(4020) = 0.28$, $p = 0.781$). In support of Hypothesis 1, the findings reported in Section 1 show that participants were less accurate, slower, showed more saccades, and larger pupil dilation on conflict, compared to no-conflict items.

3.1.2. Section 2: Conflict detection under belief instructions

In this section, we examine the effects of conflicting logical information when participants are instructed to give belief-based responses. We did this by comparing latencies, gaze movements, and dilation for (a) correct responses made when logical structure was inconsistent with the belief response (*trial type: correct conflict*), and (b) correct responses made when the logical structure was consistent with the belief response (*trial type: correct no conflict*). We found that, for *correct conflict trials*, compared to *correct no-conflict trials*, latencies were greater ($\beta = 0.47$, 95% *CI* [0.56, 0.38], $t(1549) = 10.20$, $p < .001$), there were more eye movements ($\beta = 0.40$, 95% *CI* [0.50, 0.31], $t(1589) = 8.31$, $p < .001$) and dilations were larger ($\beta = 0.05$, 95% *CI* [0.08, 0.01], $t(1545) = 2.66$, $p = .008$). In support of Hypothesis 2, we found that when people give belief-based responses to questions, they register the conflicting logical information, and this registration is reflected in slower response latencies, greater gaze movements, and larger pupil dilation. See Table 3 and Fig. B in the Appendix.

3.1.3. Section 3: Conflict detection under logic instructions

In this section, we examine the effects of conflicting information when participants were instructed to give logic-based responses. We did this by comparing incorrect conflict items, that is, those for which people gave responses in line with their beliefs despite contrasting logical information (*trial type: incorrect conflict*) to correct no-conflict items, that is, responses

Table 3
Means and standard errors, *M* (*SE*), for correct conflict and correct no-conflict trials under belief instructions

Trial	Latency	Gaze Movements	Dilation
Correct Conflict	1373.7 (23.2)	2.1 (0.1)	743.5 (11.8)
Correct No Conflict	1013.9 (18.7)	1.2 (0.04)	731.9 (8.1)

Table 4
Means and standard errors, *M* (*SE*) for incorrect conflict and correct no-conflict trials under logic instruction

Trial	Latency	Gaze Movements	Dilation
Incorrect Conflict	1146.4 (37.2)	1.3 (0.1)	778.0 (18.3)
Correct No Conflict	915.6 (16.7)	1.0 (0.04)	721.5 (7.8)

made in line with the beliefs and logic (*trial type: correct no conflict*). We found that, for *incorrect conflict*, compared to *correct no-conflict* trials, latencies were greater ($\beta = -0.41$, 95% *CI* [−0.54, −0.28], $t(1208) = -6.29$, $p < .001$), there were more eye movements ($\beta = -0.23$, 95% *CI* [−0.36, −0.10], $t(1247) = -3.41$, $p < .001$), and dilations were larger ($\beta = -0.09$, 95% *CI* [−0.14, −0.03], $t(1207) = -3.29$, $p = .001$). In support of Hypothesis 3, we found that even when people give belief-based responses to questions *about logic*, they register the conflicting logical information, and this registration is reflected in longer response latencies, greater gaze movements, and pupil dilation. See Table 4 and Fig. B in the Appendix.

4. Discussion

A core claim of Dual Process 2.0 models is that a reasoner can generate intuitions based upon both beliefs and logical rules; therein, these models challenge the long-held view that logical reasoning is the exclusive domain of effortful, Type 2 processes. Further, they claim that competition between any two intuitive responses (including those stemming from logical structure) underpins the mechanism through which Type 2 processes are engaged and conflict can be resolved (2022). Using a comprehensive range of behavioral and physiological measures, we provide evidence in support of the Dual Process 2.0 challenge and, specifically, for the hypothesis that reasoners are intuitively sensitive to logical structure and can automatically activate a logical response when engaged in reasoning under conflict.

In this study, we evaluated the intuitive nature of logical intuitions by examining the impact of conflict on measures of gaze and pupil dilation alongside behavioral measures of accuracy and latency. We also employed the instructional manipulation paradigm allowing us to examine the impact of conclusion validity on belief judgments, an effect that has been argued to arise because the logical inference is automatically activated and interferes with the generation of a belief-based response. The findings of our primary analyses were relatively clear cut; we replicated earlier research showing that conflict impacts accuracy and latency under both logical and belief-based instructions and overall belief judgments take longer than logic judgments. The effect of conflict under belief instructions and the longer latency for these judgments provides support for the claim that a competing logical inference is being cued. In addition, the effect of conflict extended to our physiological measures resulting in an increased number of gaze shifts (between the conclusion and two response options) together with increased pupil dilation.

Typically, research on conflict detection evaluates the impact of conflict on confidence and latency when participants are instructed to respond logically but instead respond based upon beliefs. Lower confidence and longer latency are indications that participants have activated the logical inference, despite giving a biased response. The use of belief instructions in this study allowed us to examine whether participants who correctly give a belief-based response also show evidence of intuitively activating the logical response, despite responding correctly on a conflict trial. Our secondary analyses showed, consistent with earlier work, that incorrect conflict trials under logical instructions are associated with longer latencies, more gaze shifts, and marginally greater pupil dilation than matched non-conflict trials. Importantly, these findings extend to the comparison of correct conflict and non-conflict trials under belief instructions, where we also observe longer latencies, more gaze shifts, and greater pupil dilation. In other words, even when participants are not engaged in logical reasoning, there is good evidence of intuitive sensitivity to logical features.

Taken together, these findings provide compelling collective evidence that reasoners are activating a competing logical response irrespective of whether they give an incorrect (under logical instructions) or correct (under belief instructions) belief-based response under conflict.

The broad convergence of findings across our behavioal and physiological measures is consistent with the claim that the detection of structural problem features that align with logical validity is automatic in nature. That is, reasoners activate the competing response rapidly and without awareness. This claim contrasts with recent research that shows that the effects of logic on liking tasks are influenced by working memory constraints, linked to cognitive capacity, and correlated with explicit logic effects (Ghasemi et al., 2022a; Hayes et al., 2020). We agree with arguments that the liking task may not be an ideal measure of intuitive logic, as the instructions lack clarity as to the basis on which reasoners should make their judgments. Hence, it is unsurprising that some participants might explicitly draw upon logical features to inform their judgment. The advantage of the manipulation employed in this study is that participants are explicitly instructed to respond based upon beliefs, and as our analyses clearly show, there remains very clear evidence that they activate a competing logical response even when responding successfully.

Does this mean that the logical response is activated intuitively? The combined evidence from this study suggests that this is, in fact, the case. Participants show longer latencies, an increased number of gaze shifts between the conclusion and response options, and some evidence of greater pupil dilation on a subset of the problems. The fact that reasoners who provide an accurate response on conflict items nevertheless show physiological markers of conflict detection is consistent with the automatic activation of a competing response. Research suggests that pupil dilation may reflect engagement of mental effort, particularly that associated with conflict detection, and more recently it has been associated with metacognitive processes linked to uncertainty and reduced confidence (Lempert et al., 2015). This is consistent with research that shows that the presence of belief–logic conflict leads to reduced confidence and lower feelings of rightness (Thompson et al., 2011). Recent research shows that perceptual ambiguity can lead to pupil dilation even when the observer remains consciously unaware of this ambiguity (Graves, Egre, Pressnitzer, & de Gardelle, 2021). A task for future research will be to examine whether reasoners are similarly unaware of a competing logical response under conflict when they give belief-based responses on this task.

Finally, we note recent research that claims that logical intuitions of the kind that we describe here do not arise because of the activation of logical rules but instead because of more superficial structural cues in the problem (Meyer-Grant et al., 2022). These authors show that logic effects on liking judgment tasks arise because on valid arguments there is a match between the polarity of the premises and the conclusions, which is not present on invalid versions of the same arguments. Their explanation draws upon an "atmosphere heuristic" and not logic as the principal cue that determines liking evaluations. This claim aligns with a similar "matching" account developed in recent research by Ghasemi, Handley, Howarth, Newman, and Thompson (2022b) who argued that the effect of validity on belief judgments similarly arose because of a polarity match on valid arguments, an effect that was extended to invalid conditional arguments where the same structural features were present. Interestingly, in both studies, the same non-logical features influenced explicit logical judgments, a finding that aligns with classic work in the field of deductive reasoning (Evans, Newstead, & Byrne, 1993; Wetherick & Gilhooly, 1995).

While our current work cannot directly discriminate between these heuristic-based accounts of logical intuition effects, we note that our study also included disjunctive arguments, where a matching heuristic of the kind described above cannot apply (the polarity of the conclusion and the premises mismatch). Although there were some minor differences in the effects observed between conditionals and disjunctives, the patterns of conflict detection across the majority of measures were similar for both connectives. It is, of course, possible that a different heuristic operates with disjunctive arguments, and we recognize that future research might establish that logical intuitions of the kind we have examined in this paper do, in fact, also arise through non-logical processes. Irrespective of this, the current research demonstrates clearly that competing intuitions (whether based on logic or heuristics) are activated rapidly while reasoning and their co-occurrence is evidenced by both behavioral and physiological markers.

While these findings have a direct bearing on claims of logical intuition, they also have relevance to broader questions in cognitive science concerning the processes underlying conflict detection and cognitive control. In line with behavioral (Bago & De Neys, 2017), psychophysiological (Banks & Hope, 2014), and neuroscience findings (Carter & van Veen, 2007), our data provide additional evidence for conflict detection occurring during heuristic belief-based judgments, in the absence of logical responding (De Neys, 2012). The findings support contemporary dual process models and are consistent with claims that cognitive control and conflict detection rely on distinct processing mechanisms (Matsumoto & Tanaka, 2004). They further demonstrate the value of eye movements and pupil dilation in the study of the components of attentional control.

Open Research Badges

This article has earned Open Data and Open Materials badges. Data and materials are available at https://osf.io/tsbp5/?view_only=fe153d8d4b74480587584c7484b3d2ea.

Notes

1 To prevent extreme viewing angles distorting the pupil measurements, only pupil measurements that occurred when the participant was fixating, that is, the eye was not in movement, and when they were looking within the "conclusion," AOI were included in the analysis.
2 To see graphed results and how these effects interact with problem type (conditionals, disjunctives) please see the Appendix.
3 All linear models estimated using Restricted Maximum Likelihood (REML) and nloptwrap optimizer.
4 All analyses were conducted in RStudio (RStudio Team, 2022) using the lme4 package (Bates, Mächler, Bolker, & Walker, 2015). Models were estimated using Maximum Likelihood (ML) and Nelder–Mead optimizer.

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Supporting Information

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Supplementary material

Appendix

Visualized descriptive results

In Fig. A, we present the means and standard errors of our Section 1 variables. They demonstrate that across our key dependent variables: accuracy, latencies, gaze movements, and pupil dilation, we find effects of conflict.

In Fig. B, we present the means and standard errors of our Section 2 (top panel, a to c) and Section 3 (bottom panel, d to f) variables. They demonstrate that across latencies, gaze movements, and pupil dilation, we find effects of conflicting logical information even when respondents are providing belief-based or belief-aligned responses.

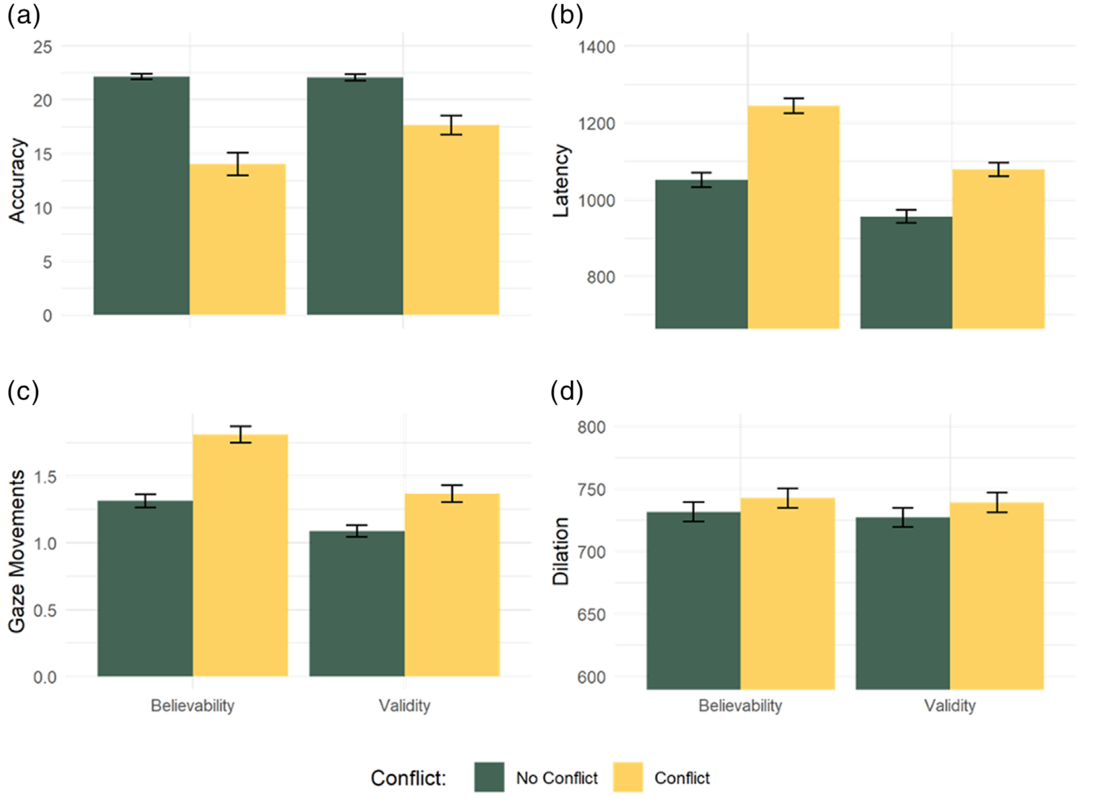

Fig. A. We found that for conflict versus no-conflict items, (a) accuracy was lower, (b) latencies were longer, (c) there were greater gaze movements, and (d) dilations were larger. Error bars = +/− 1 *SE*.

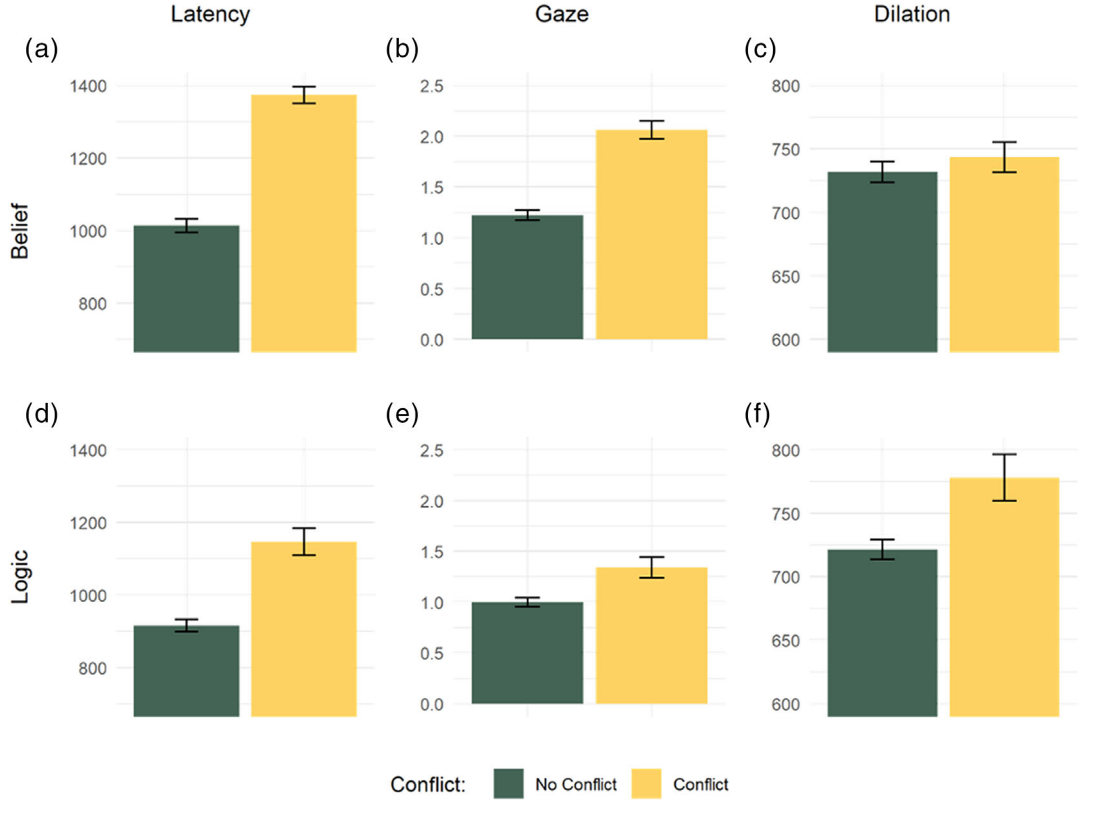

Fig. B. We found that under belief instructions (top panels: a to c), latencies, gaze movements and dilation were greater for correct conflict than correct no-conflict trials. Similarly, for logic instructions (bottom panels: d to f), latencies, gaze movements and dilation were greater for incorrect conflict than correct no-conflict trials. Error bars = +/− 1 *SE*.