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Belief inhibition in children's reasoning: Memory-based evidence

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ABSTRACT

Adult reasoning has been shown as mediated by the inhibition of intuitive beliefs that are in conflict with logic. The current study introduces a classic procedure from the memory field to investigate belief inhibition in 12- to 17-year-old reasoners. A lexical decision task was used to probe the memory accessibility of beliefs that were cued during thinking on syllogistic reasoning problems. Results indicated an impaired memory access for words associated with misleading beliefs that were cued during reasoning if syllogisms had been solved correctly. This finding supports the claim that even for younger reasoners, correct reasoning is mediated by inhibitory processing as soon as intuitive beliefs conflict with logical considerations.

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Introduction

Although humans are considered as rational compared with other species, we often show irrational behavior. Consider, for example, the popularity of lottery games. Even though it is generally known that the chances of monetary gain in these games are nearby zero, it is surprising how many people buy lottery tickets every week. Despite many projects pointing to the irrationality of participating in gambling games, people do not seem to be able to suppress misleading beliefs in personal luck and continue gambling.

The issue of human rationality has captured a lot of attention in cognitive research over the past decades. Hundreds of studies showed that well-educated adults' reasoning is often biased by intuitive thinking (Evans, 2003; Kahneman & Tversky, 1973; Sloman, 1996). When solving various kinds of

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reasoning tasks, people tend to rely on intuitive beliefs (i.e., heuristics) instead of on more demanding analytical reasoning. Although mere intuitive thinking can often be useful, it will sometimes cue logically incorrect responses. For example, when evaluating the validity of a deductive syllogism (e.g., "All fruit is healthy. Apples are fruit. Therefore, apples are healthy."), people intuitively base their judgment on the believability of the conclusion. When the response cued by these intuitions is consistent with logical considerations, this will lead to the correct response. In the syllogism above, for instance, people will accept the conclusion based on their prior beliefs, and this is also the correct response because the conclusion is valid. However, as soon as cued intuitions are in conflict with logical considerations, intuitive thinking will lead to the incorrect response or a belief bias. Consider the following example: "All mammals have lungs. Cows have lungs. Therefore, cows are mammals." Although the conclusion in this syllogism is logically invalid and should be rejected, people will be tempted to accept it based on its believability.

Several authors suggest that this phenomenon of human irrationality should be attributed not to a failure of analytical reasoning per se but rather to a lack of inhibition of intuitive beliefs (e.g., Evans, 2008; Houdé, 1997, 2000; Moutier, Angeard, & Houdé, 2002; Reyna et al., 2003; Stanovich & West, 2000). They suppose that when analytic and heuristic thinking cue different responses, it is necessary to suppress the heuristic beliefs in order to make a logically correct response. Indeed, there is some evidence for the claim that sound reasoning requires the inhibition of intuitive beliefs. Neuroimaging studies showed that successfully overcoming belief bias is related to increased activity in the lateral prefrontal cortex (LPFC) (e.g., De Martino, Kumaran, Seymour, & Dolan, 2006; De Neys, Vartanian, & Goel, 2008; Goel & Dolan, 2003; Houdé et al., 2000; Prado & Noveck, 2007; Sanfey, Rilling, Aronson, Nystrom, & Cohen, 2003), which is the same brain region that is supposed to be mediating inhibitory processing (e.g., Aron, Robbins, & Poldrack, 2004). Moreover, individual difference studies demonstrated that people with higher working memory capacities are more successful in overcoming a belief bias during reasoning (e.g., De Neys, 2006; De Neys & Verschueren, 2006; Newstead, Handley, Harley, Wright, & Farrelly, 2004; Stanovich & West, 2000). Because inhibition is one of the key working memory functions (Baddeley, 2000), this suggests that inhibitory processing plays an important role in correct reasoning.

However, as noted by De Neys and Franssens (2009), the above studies do not provide any direct evidence for the claim that people actually discard their intuitive beliefs during reasoning. De Neys and Franssens addressed this problem by introducing a classic procedure from the memory field to study belief inhibition. Memory studies have long established that the suppression of information temporarily distorts the access to this information in memory (e.g., MacLeod, Dodd, Sheard, Wilson, & Bibi, 2003; Neill, 1997; Tipper, 1985). Therefore, De Neys and Franssens noted that an actual inhibition of intuitive beliefs during reasoning should also lead to a temporarily impaired accessibility of these beliefs in memory. De Neys and Franssens decided to present a measure of memory access after reasoning to test the inhibition claim. Their study used classic reasoning problems in which intuitions either conflicted with logic or did not (i.e., conflict vs. no-conflict problems), just as in the introductory syllogistic examples. Hence, in the conflict problems, the intuitive beliefs cued the logically incorrect response, so inhibition of these beliefs was necessary for sound reasoning (e.g., an invalid syllogism with a believable conclusion such as the following: "All flowers need water. Roses need water. Therefore, roses are flowers."). In the no-conflict problems, the intuitions cued the correct response, so no belief inhibition was required (e.g., a valid syllogism with a believable conclusion such as the following: "All birds have wings. Sparrows are birds. Therefore, sparrows have wings."). To test for participants' memory access to intuitive beliefs, the researchers presented a lexical decision task after each reasoning problem. In this task, strings of letters were presented and participants needed to decide whether these strings were words or not. Some of these strings were so-called "target" words that were related to the intuitive beliefs cued in the previous reasoning problem (e.g., "rose"). The crucial question concerned the time needed to make a lexical decision for these target words. Because inhibition of information should lead to an impaired accessibility of this information in memory, one would expect longer lexical decision times for words related to the inhibited information. Consistent with this hypothesis, De Neys and Franssens indeed observed longer reaction times for target words in the lexical decision task after participants had solved conflict problems than after they had solved no-conflict problems. This pattern supports the claim that intuitive beliefs are inhibited during reasoning on the conflict problems.

The findings of De Neys and Franssens (2009) provided direct evidence for the postulation of a belief inhibition process in human reasoning. However, so far the experiments have focused exclusively on the performance of young adults. In the developmental field, it is well established that inhibitory capacities increase from childhood to young adulthood (e.g., Bedart et al., 2002; Christ, White, Mandernach, & Keys, 2001; Dempster & Brainerd, 1995), and these improved inhibitory capacities have been shown to be accompanied by increased performance on reasoning problems in which intuitive beliefs and logic conflict (e.g., Barrouillet, Markovits, & Quinn, 2001; De Neys & Everaerts, 2008; De Neys & Van Gelder, 2008; Houdé, 2007; Klaczynski & Narashimham, 1998; Kokis, Macpherson, Toplak, West, & Stanovich, 2002). However, even young participants sometimes manage to reason correctly on conflict problems. It has been shown that correct reasoning children typically have the highest inhibitory capacities (e.g., De Neys & Van Gelder, 2008; Handley, Capon, Beveridge, Dennis, & Evans, 2004; Kokis et al., 2002); however, just as with adults, in the absence of any direct memory-based evidence, this does not necessarily entail that intuitive beliefs were indeed inhibited during thinking.

Recently, Moutier, Plagne-Cayeux, Melot, and Houdé (2006) started to address this issue and found some more direct evidence for the presence of inhibitory processing in correct thinking in children. In this study, children were presented with pairs of subsequent conflict and no-conflict syllogistic reasoning problems that shared the same conclusions and, hence, cued the same intuitive beliefs (e.g., conflict syllogism: ''All elephants are hay eaters. All hay eaters are light. So all elephants are light''; no-conflict syllogism: ''All elephants are hay eaters. No hay eaters are light. So all elephants are light.''). For half of the participants, a conflict problem was always followed by a no-conflict problem; for the other half, this order was reversed. The researchers tested the inhibition claim by looking for a negative priming effect on the no-conflict problems. This refers to an impaired performance on a no-conflict problem when a conflict problem with the same conclusion was solved previously. Because reasoning on a no-conflict problem benefits from intuitive thinking, performance on this type of problem will be impaired if intuitive beliefs are not accessible during reasoning. Thus, if beliefs were inhibited when solving a conflict problem, performance on the immediately subsequent no-conflict problem should be impaired because the inaccessibility of intuitive beliefs will prevent intuitive thinking. The results indeed showed that performance on no-conflict syllogisms was worse when a conflict problem with the same cued intuitions was previously solved correctly.

Although Moutier and colleagues' findings present an original initial validation of the inhibition claim in children's reasoning, further testing is needed to rule out possible confounds. Note that although the authors assumed that a worse performance on no-conflict problems after correctly solving a conflict problem resulted from an inhibition process, it might also have resulted from the mere previous presentation of the conflict problem. Because solving a conflict problem is cognitively demanding, performance on the subsequent no-conflict problem might have been hampered because the participants were cognitively exhausted. That is, it is not necessarily the case that the impaired performance on the subsequent no-conflict problem resulted from an inaccessibility of the beliefs per se. Dealing with conflicting cues might make the conflict problems demanding, which may explain the impaired performance on the subsequent problem. The current study addressed this concern by adopting the method of De Neys and Franssens (2009) to examine memory-based evidence for an inhibition process in children's reasoning.

To test our hypotheses, we presented classic reasoning problems followed by a lexical decision task to 12- to 17-year-old reasoners. Participants needed to evaluate the validity of syllogistic reasoning problems. Half of the problems were conflict problems, and the other half were no-conflict problems. After every syllogism, we presented a lexical decision task in which letter strings were shown and the participants needed to decide whether these strings were words or not. Half of the presented words were target words that were closely related to the intuitive beliefs that were cued in the previous syllogism, and the other half were completely unrelated to these beliefs. Just as in the research of De Neys and Franssens (2009), the lexical decision times for the target words allowed us to test the inhibition claim. If correct reasoning in children is mediated by an inhibition process, a lexical decision effect should be apparent on the target words after correctly solving a conflict problem. That is, the lexical

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decision times for the target words after these problems should be slower than those after no-conflict problems. Because unrelated words will not have been inhibited during reasoning, lexical decision times for these unrelated words should not differ after solving conflict and no-conflict problems.

Method

Participants

A total of 54 young adolescents (mean age = 12.26 years, *SD* = 0.48, 30 girls and 24 boys), 51 middle adolescents (mean age = 14.49 years, *SD* = 0.64, 23 girls and 28 boys) and 54 late adolescents (mean age = 16.81 years, *SD* = 0.68, 25 girls and 29 boys) volunteered to participate in the study. All participants were recruited at a Belgian high school and were native Dutch speakers.

Materials

Reasoning task

The syllogistic reasoning task was based on the work of Sá, West, and Stanovich (1999) and Markovits and Nantel (1989). Participants were presented with eight syllogistic reasoning problems. In four of these problems, the believability of the conclusion was in conflict with logic. Two of these conflict problems had a believable and invalid conclusion (e.g., "All flowers need water. Roses need water. Therefore, roses are flowers."), and two had an unbelievable and valid conclusion (e.g., "All mammals can walk. Whales are mammals. Therefore, whales can walk."). In the other four problems, the believability of the conclusion was consistent with its logical status. Two of these no-conflict problems had a believable and valid conclusion (e.g., "All birds have wings. Sparrows are birds. Therefore, sparrows have wings."), and two had an unbelievable and invalid conclusion (e.g., "All African countries are warm. Spain is warm. Therefore, Spain is an African country."). The following item format was adopted:

All birds have wings.
Sparrows are birds.
Therefore, sparrows have wings.

1. The conclusion follows logically from the premises.
2. The conclusion does not follow logically from the premises.

A complete overview of all eight problems can be found in Appendix A.

Lexical decision task

After participants had solved a reasoning problem, they were presented with a total of 24 letter strings. Participants were asked to indicate whether each string was a word or not by pressing one of two response keys as quickly as possible. Half of the letter strings were nonwords (e.g., "dxch"), and the other half were words. Six of the presented words were target words that were closely related to the beliefs that were cued in the reasoning task. These targets were core words from the conclusion or strongly associated words (e.g., "wing" or "feathers" in the above example). The other six words were completely unrelated to the beliefs that the conclusion referred to. All words were adopted from Experiment 1 of De Neys and Franssens (2009). These words were selected with the help of a Dutch word association index (De Deyne & Storms, 2008). The classifications of target and unrelated words were validated by two raters, and words for which judgments diverged were replaced with an alternative that all parties agreed on. The crucial prediction concerns the lexical decision time for target words after solving conflict versus no-conflict problems. Because different target words were used for conflict and no-conflict problems, De Neys and Franssens conducted a pilot study to establish that there were no a priori lexical differences between the selected target words. Participants were presented with the lexical decision task without a preceding reasoning task. Results showed that lexical decision times for the target words of conflict and no-conflict problems did not differ. A complete overview of the selected words can be found in Appendix A.

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Procedure

Participants were tested two at a time while seated in opposite directions behind a computer screen. First they were familiarized with the task format. An example of a syllogistic reasoning problem was shown, and participants practiced the lexical decision task. It was clarified that both tasks would alternate in the actual experiment. Standard deductive reasoning instructions were provided, stressing that the premises always needed to be assumed as true and that a conclusion should be accepted only if it followed logically from the premises.

After this short introduction, the actual experiment started with the presentation of a syllogistic reasoning problem. Each syllogism was presented using a serial presentation format (e.g., De Neys & Franssens, 2009; Goel & Dolan, 2003). The first premise appeared first, and after 3 s the second premise followed. Again after 3 s, the conclusion and response options appeared. The complete problem remained on the screen until participants responded by pressing an answer key. The eight different reasoning problems were presented in random order.

The average syllogistic response time in the current experiment was 6.57 s ($SD = 4.52$), so every reasoning trial lasted approximately 12.5 s. The average response time was longer for conflict problems than for no-conflict problems, $F(1, 158) = 5.21$, $p < .025$, $\eta_p^2 = .03$. However, control analyses established that for neither conflict nor no-conflict problems was the critical lexical decision time for target or unrelated words affected by the time spent solving the reasoning problems (see Appendix B). Reasoning response times were associated with reasoning accuracy on the conflict problems ($r = .43$, $p < .0001$), indicating that participants who reasoned more accurately also took longer to solve the syllogisms. However, control analyses established that reasoning accuracy (whether or not controlled for syllogistic response time) did not affect lexical decision time for target or unrelated words. Interested readers can find an overview of these control analyses in Appendix B.

After the response on the reasoning task was entered, participants were presented with the lexical decision task. The 24 letter strings that were selected for the reasoning problem that had been solved were presented in random order. Strings were presented in the center of the screen, and participants were asked to respond as fast as possible while avoiding mistakes.

Finally, at the end of the experiment, the conclusions of the eight syllogisms in the reasoning task were presented on a paper sheet, and participants were asked to rate their believability. This allowed us to make sure that the conclusions cued the intended beliefs in all age groups. Conclusions were rated on a scale from 1 to 10, with 1 reflecting *very unbelievable* and 10 reflecting *very believable*. Results showed that the believability scores were very high for the believable conclusions ($M = 9.71$, $SE = 0.05$) and very low for the unbelievable conclusions ($M = 0.67$, $SE = 0.09$). This was true for all age groups; there was no interaction effect between type of conclusion (believable or unbelievable) and age group (young, middle, or late adolescence), $F(2, 156) = 0.32$, $p > .70$. Interested readers can find the believability scores of the different age groups in Appendix C.

Results

Reasoning task

Performance on the reasoning task was as expected. As Table 1 shows, correct response rates on the conflict problems were on average lower than those on the no-conflict problems, $F(1, 156) = 247.90$, $p < .001$, $\eta_p^2 = .61$. There was a main effect of age (young vs. middle vs. late adolescence, between participants), $F(2, 156) = 20.28$, $p < .001$, $\eta_p^2 = .21$, and a significant interaction effect between this factor and type of problem (conflict vs. no-conflict, within participants), $F(2, 156) = 8.65$, $p < .001$, $\eta_p^2 = .10$. Consistent with previous findings, planned contrasts showed that performance on conflict problems increased from young to late adolescence, $F(2, 158) = 17.76$, $p < .001$, $\eta_p^2 = .60$, whereas correct response rates on no-conflict problems did not differ between the different age groups, $F(2, 158) = 1.57$, $p = .21$. Post hoc Newman–Keuls tests on the conflict problem scores established that young adolescents were outperformed by both middle and late adolescents, whereas performance further increased from middle to late adolescence (all ps $< .01$). A trend analysis confirmed that the age effect on the conflict problems was linear in nature, $F(1, 156) = 34.86$, $p < .0001$, $\eta_p^2 = .18$.

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Table 1
Reasoning accuracy (% correct) in the different age groups.

Age group	Accuracy (%)	
	Conflict	No-conflict
Young adolescence	19 (.25)	83 (.22)
Middle adolescence	39 (.35)	90 (.16)
Late adolescence	55 (.32)	88 (.17)

Note: Standard errors are shown in parentheses.

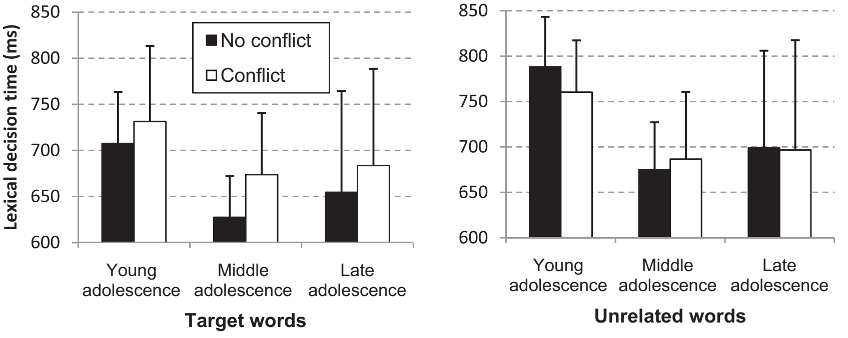

Fig. 1. Average lexical decision times for target words and unrelated words after correctly solving no-conflict problems and conflict problems. Error bars are standard errors.

Lexical decision task

The presented letter strings were almost always correctly classified as words or nonwords (young adolescents: 94%, $SD = .04$; middle adolescents: 96%, $SD = .03$; late adolescents: 96%, $SD = .09$). The incorrectly classified strings were excluded from the analyses.

Our main interest concerned the lexical decision times for the target and unrelated words (i.e., words that were and were not associated with the cued beliefs in the reasoning task). Because we are interested in inhibitory processing during correct reasoning, our analysis focused on lexical decision times after correctly solved reasoning problems. Fig. 1 shows the average decision times for the target and unrelated words after correctly solving conflict and no-conflict problems. We performed a 2 (Type of Problem: conflict vs. no-conflict, within participants) $\times$ 2 (Type of Word: target vs. unrelated, within participants) $\times$ 3 (Age: young vs. middle vs. late adolescence, between participants) mixed model analysis of variance (ANOVA) on these data.

As expected, there was a main effect of type of word, $F(1, 100) = 28.49$, $p < .001$, $\eta_p^2 = .22$. Lexical decision times for target words were consistently faster than those for unrelated words. Not surprisingly, target words were recognized faster because these words were primed in the reasoning task. The main effects of age, $F(2, 100) = 1.81$, $p = .17$,[1] and type of problem, $F(2, 100) = 1.87$, $p = .18$, were not significant. More important was the interaction effect between type of problem and type of word, $F(1, 100) = 9.00$, $p < .01$, $\eta_p^2 = .08$. Lexical decision times for target words were on average longer after correctly solving conflict problems compared with no-conflict problems, $t(102) = 2.82$, $p < .01$. This indicates that intuitive beliefs cued during correct reasoning were inhibited as soon as they were in conflict with logic. As demonstrated in Fig. 1, lexical decision times for unrelated words that had not been cued during reasoning did not differ depending on the type of problem solved, $t(102) = -0.33$, $p = .74$. Therefore, we

[1] The lack of a main effect of age suggests that overall lexical decision time did not differ significantly for young adolescents ($M = 746.89$, $SE = 33.99$), middle adolescents ($M = 665.75$, $SE = 27.96$), and late adolescents ($M = 683.43$, $SE = 24.04$). Of course, a true main effect of age might be masked here by the large variance and/or relatively small n after the exclusion of incorrectly solved trials.

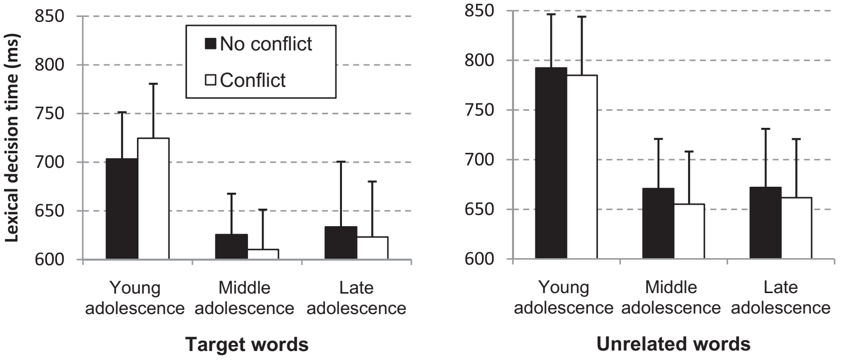

Fig. 2. Average lexical decision times for target words and unrelated words after correctly solving no-conflict problems and incorrectly solving conflict problems. Error bars are standard errors.

can conclude that correctly solving a conflict problem does not simply cause a general memory access impairment. As might be expected, only access to misleading intuitive beliefs was distorted after solving these problems.

The three-way interaction effect among type of problem, type of word, and age did not reach significance, $F(2, 100) = 0.21$, $p = .82$. All age groups took more time to make a lexical decision for target words after conflict problems had been solved correctly compared with no-conflict problems, and this effect was not found for unrelated words in any of the groups. In sum, evidence for inhibitory processing during correct thinking was found in all children regardless of their age.

The above results provide the first memory-based evidence for belief inhibition during correct reasoning in adolescents. For completeness, we also analyzed the lexical decision times when participants had been reasoning incorrectly on the conflict problems. Lexical decision times after incorrectly solved conflict problems were compared with those after solving no-conflict problems (see Fig. 2). Again, we performed a 2 (Type of Problem: conflict vs. no-conflict, within participants) × 2 (Type of Word: target vs. unrelated, within participants) × 3 (Age: young vs. middle vs. late adolescence, between participants) mixed model ANOVA on these data.

Just as in the previous analyses, we found a main effect of type of word, $F(1, 135) = 106.03$, $p < .001$, $\eta_p^2 = .44$. Lexical decision times for target words were again faster than those for unrelated words. There was also a main effect of age, $F(2, 135) = 21.33$, $p < .001$, $\eta_p^2 = .24$. Planned comparisons showed that young adolescents' decision times were slower than those of middle adolescents, $t(103) = 6.43$, $p < .001$, and late adolescents, $t(106) = 2.22$, $p < .05$. More important, the main effect of type of problem, $F(1, 135) = 1.06$, $p = .31$, and the interaction of this factor with type of word, $F(1, 135) = 1.12$, $p = .29$, did not reach significance. Hence, in contrast to the correctly solved problems, we did not find differences between lexical decision times for targets from conflict problems compared with no-conflict problems. That is, when adolescents failed to inhibit the belief-based response and gave the incorrect response, memory access to these uninhibited beliefs was also not impaired. Finally, the three-way interaction effect among type of problem, type of word, and age also did not reach significance, $F(2, 135) = 1.18$, $p = .31$.

Discussion

The current research focused on the inhibition of misleading beliefs in children's reasoning. We adopted a procedure from the memory field that had been introduced by De Neys and Franssens (2009) as a method to study belief inhibition in reasoning. Probing the accessibility of beliefs that were cued during reasoning allowed us to look for direct memory-based evidence for the inhibition claim. We observed that correct reasoning in children was accompanied by an impaired access to beliefs that conflicted with logic. When a syllogism with misleading beliefs (i.e., beliefs cueing the incorrect response) was solved correctly, lexical decisions for target words associated with these beliefs took longer than when a syllogism with non-misleading beliefs (i.e., beliefs cueing the correct response) was solved. This suggests that in children, correctly solving a reasoning problem is mediated by the inhibition of beliefs that cue the logically incorrect response. These findings are in line with the claim made by Moutier and colleagues (2006), who looked for an inhibition process in children's thinking adopting a negative priming paradigm. However, the results in their research could not unambiguously be attributed to inhibitory mechanisms because it could not be excluded that the observed patterns may have been driven by cognitive exhaustion rather than inaccessibility of intuitive beliefs. The direct probing of children's memory accessibility in the current study allowed us to eliminate this possible confound.

However, the suppression of misleading beliefs occurred only if children were able to give the logically correct response. When a conflict problem was solved inaccurately (i.e., when the postulated inhibition was not successful), lexical decision times for target words of these problems were no longer different from those of no-conflict problems. Interestingly, this contrasts with the performance of adults, who seem to initiate a belief inhibition process as soon as reasoning requires that intuitive beliefs are disregarded regardless of reasoning performance (De Neys & Franssens, 2009). Indeed, De Neys and Franssens (2009) observed that even when adults gave an incorrect response, they showed a slight but significant increase in lexical decision times after solving conflict problems. De Neys and Franssens suggested that this indicated that even when adults are biased, they had at least initiated an inhibition process but simply failed to complete it. The current findings suggest that younger reasoners do not yet show this inhibition engagement when they fail to solve the problem correctly. This might imply that biased younger reasoners have difficulties in detecting the necessity to engage in inhibitory processing per se (e.g., De Neys, Cromheeke, & Osman, 2011; De Neys, Moyens, & Vansteenwegen, 2010; Santesso & Segalowitz, 2008) or simply that younger reasoners lack sufficient resources for such engagement despite initial detection of its necessity. Nevertheless, the primary focus of the current study concerned correctly solved reasoning problems. The current findings validate the claim that even for younger reasoners, correctly solving reasoning problems in which belief and logic conflict is associated with an inhibition of misleading beliefs in memory.

Finally, we should clarify a possible misconception with respect to our findings. In the current article, we observed that the critical lexical decision effect does not vary with age. Clearly, this does not imply that inhibitory processing does not develop with age. First, as we noted, numerous studies have demonstrated that children's inhibitory capacities increase with age (e.g., Barrouillet et al., 2001; Bedart et al., 2002; Christ et al., 2001; Dempster & Brainerd, 1995; De Neys & Van Gelder, 2008; Houdé, 2007; Klaczynski & Narashimham, 1998; Kokis et al., 2002). Consistent with these findings, we also observed in the current study that reasoning accuracy on the critical conflict problems (where inhibition is assumed to be mandatory for sound reasoning) increases with age. Hence, throughout development, children do become more successful at inhibiting misleading beliefs. However, what we tried to examine in the current study is whether during the few times when younger children do manage to give a correct response, their sound reasoning is mediated by an inhibition process. Consistent with this hypothesis, we found that the critical lexical decision time increase on target words after correctly solving conflict problems is present across age. Second, one should also bear in mind that the lexical decision data should not be used to make claims about the quality of the inhibition process. That is, the fact that younger and older adolescents show a similar lexical decision increase does not imply that the inhibitory processing was equally "good" or "efficient." More specific, it is paramount to note here that our procedure only allows us to make a categorical claim about whether participants engage in an inhibition process or not. If participants engage in a belief inhibition process, we can argue that they should show an impaired access to target words after solving conflict problems. However, the size of the impairment cannot be taken as a mere measure of the extent or quality of the inhibition process. In essence, the memory inaccessibility is a negative by-product of the belief discarding process. It is possible, for example, that more gifted or older participants pay a less severe price for the inhibition (e.g., accessibility is easier restored). Hence, the fact that younger and older reasoners show a similar impairment does not necessarily imply that the inhibition process was completely similar. The observed impairment across all ages does allow us to conclude that everyone indeed engaged in an inhibition process. If correct responding on conflict problems for younger children did not entail a belief inhibition process, they should not show any lexical impairment. It is this critical point that the current study highlighted.

In closing, we should point to a number of limitations of our study. The current study is the first one to introduce the lexical decision methodology to study children's inhibitory processing during reasoning. Obviously, this implies that the current findings will need to be replicated in future studies that could test larger samples or a wider age range. In addition, one might also note that the current findings will need to be generalized to other reasoning and decision-making tasks. This study focused exclusively on deductive syllogisms. Although this is one of the most popular tasks for studying belief bias, it would be interesting to test the generalizability of the findings across a wider range of tasks. Clearly, in the absence of such future replication and generalization, the current findings need to be interpreted with some caution. Nevertheless, when keeping these caveats in mind, we do believe that our findings present a critical novel validation of the claim that correct reasoning is mediated by inhibitory processing across development.

Appendix A. Overview of reasoning problems and selected target and unrelated words (translated from Dutch)

Conflict problems

1.
All flowers need water.
Roses need water.
Roses are flowers.
Target words: rose, petal, garden, flower, plant, bush.
Unrelated words: wolf, competition, date, stone, axe, cooked.

2.
All things with an engine need oil.
Cars need oil.
Cars have an engine.
Target words: car, steer, drive, engine, train, fire.
Unrelated words: smart, annoying, tea, slum, mint, wheat.

3.
All mammals can walk.
Whales are mammals.
Whales can walk.
Target words: whale, dolphin, ocean, run, marathon, walk.
Unrelated words: firm, head, enough, story, flexible, rattle.

4.
All vehicles have wheels.
A boat is a vehicle.
A boat has wheels.
Target words: boat, canal, ship, wheel, drive, tire.
Unrelated words: circle, forever, curve, night, pants, people.

No-conflict problems

5.
All African countries are warm.
Spain is warm.
Spain is an African country.
Target words: Spain, sea, beach, Africa, sun, lion.
Unrelated words: telephone, shoe, hole, joke, spoon, bed.

6.
All meat products can be eaten.
Apples can be eaten.
Apples are meat products.
Target words: apple, pear, fruit, meat, food, cow.
Unrelated words: child, cloud, idol, psychologist, elite, fashion.

7.
All birds have wings.
Crows are birds.
Crows have wings.
Target words: crow, raven, black, wing, fly, feathers.
Unrelated words: war, alphabet, calf, aniseed, room, video.

8.
All things that are smoked are bad for your health.
Cigarettes are smoked.
Cigarettes are bad for your health.
Target words: cigarette, smoke, cancer, health, doctor, ill.
Unrelated words: ball, optimum, monastery, tender, difference, sketch.

Appendix B. Overview of additional control analyses

Table B1. Correlations between lexical decision latencies and reasoning task performance.

Reasoning task	Lexical decision task	
	Target words	Unrelated words
Conflict syllogisms		
Response time	.08	.14*
Response accuracy	−.03 (−.07)	−.03 (−.10)
No-conflict syllogisms		
Response time	.02	−.01
Response accuracy	−.01 (−.00)	−.04 (−.04)

Note: Partial correlations controlled for syllogistic control time are shown in parentheses. None of the correlations reached significance at the .05 level (*$p < .09$).

Appendix C. Believability scores for conclusions in syllogistic reasoning problems

Table C1. Believability scores for unbelievable and believable conclusions.

	Believability score
Believable conclusions	
Young adolescents	9.79 (0.58)
Middle adolescents	9.76 (0.57)
Late adolescents	9.59 (0.75)
Unbelievable conclusions	
Young adolescents	0.87 (1.12)
Middle adolescents	0.64 (1.23)
Late adolescents	0.50 (0.88)

Note: Standard errors are shown in parentheses.

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