# HEURISTICS, BIASES, AND THE DEVELOPMENT OF CONFLICT DETECTION DURING REASONING

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Word count : 8590 words

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**ABSTRACT**

Although human reasoning is often biased by intuitive heuristics, recent studies on conflict detection during thinking suggest that adult reasoners detect the biased nature of their judgments. Despite their illogical response, adults demonstrate a remarkable sensitivity to possible conflict between their heuristic judgment and logical or probabilistic norms. In this chapter I review emerging work on the development of this critical conflict or bias sensitivity. Taken together, the available evidence suggest that a lack of heuristic bias detection might be a key factor that distinguishes older and younger reasoners.

# INTRODUCTION

Human judgment is easily biased. Consider, for example, the controversy that surrounded the introduction of beach volleyball as an Olympic sport at the Atlanta 1996 games. A lot of critics objected and argued that they simply could not rate beach volleyball as a real sport. It was considered to be nothing more than a fun past-time that you play on the beach on holiday (Coren, 2012). I've always found this striking because beach volleyball is both physically and mentally one of the most demanding sports that I know. To excel players need speed, strength, excellent technical skills, and the ability to play tactically as a pair. Indeed, a close look at the impressive physique of the top players makes it clear that - in contrast with, let's say, the average slugger in baseball or lineman in football - you need to be a highly trained athlete to make it in this game. Hence, if you deliberately reflect on it for a minute, there are very good reasons to classify beach volleyball as a real sport. The problem, however, seems to be that intuitively, beach volleyball is readily associated with prototypical "leisure" concepts such as "beach", "fun", and "holiday". After all, the game is played on a sand court, players dress in typical beachwear, and major tournaments are held at exotic destinations such as Rio de Janeiro, Hawaii, or Santa Barbara. These automatic intuitive associations seem to have an irresistible biasing pull on people's judgment (Lewis, 2008).

Decades of reasoning and decision-making research have shown that similar intuitive thinking is biasing people's reasoning in a wide range of logical and probabilistic reasoning tasks (Evans, 2008; Evans & Over, 1996; Kahneman & Frederick, 2005). Consider, for example, the following adaptation of the famous base-rate neglect (Kahneman & Tversky, 1973) problem:

> A psychologist wrote thumbnail descriptions of a sample of 1000 participants consisting of 5 women and 995 man. The description below was drawn randomly from the 1000 available descriptions.
>
> Sam is a 25 years old writer who lives in Toronto. Sam likes to shop and spends a lot of money on clothes.
>
> What is most likely?
> a. Sam is a woman.
> b. Sam is a man.

Intuitively, many people will be tempted to conclude that Sam is a woman based on stereotypical beliefs cued by the description. However, given that there are far more males than females in the sample (i.e., 995 out of 1000) the statistical base-rates favor the conclusion that a randomly drawn individual will most likely be a man. Hence, logically speaking, taking the base-rate into account should push the scale to the “man” side. Unfortunately, just as in the beach volley case, educated reasoners are typically tricked by their intuition and fail to solve the problem correctly (e.g., De Neys & Glumicic, 2008). In general, human reasoners seem to have a strong tendency to base their judgment on fast intuitive impressions rather than on more demanding, deliberative reasoning. Although this intuitive or so-called “heuristic” thinking might sometimes be useful, it can also cue responses that conflict with more logical or probabilistic considerations and bias our thinking (Evans, 2003, 2010; Kahneman, 2011; Stanovich & West, 2000).

Interestingly, however, recent studies on conflict detection during thinking show that despite the omnipresent bias, adults demonstrate a remarkably sensitivity to violations of logical and probabilistic principles when they reason (e.g., Bonner & Newell, 2010; De Neys & Franssens, 2009; De Neys & Glumicic, 2008; Handley, Newstead, & Trippas, 2011; Morsanyi & Handley, 2012; Stupple & Ball, 2008; Villejoubert, 2009). That is, although people are often biased and fail to give the correct response, they at least seem to detect that their intuitive heuristic response is questionable. For example, giving an erroneous heuristic response has been shown to result in increased autonomic activation (e.g., De Neys, Moyens, & Vansteenwegen, 2010), increased activation of brain regions supposed to be mediating conflict detection (e.g., De Neys, Vartanian, & Goel, 2008), and decreased response confidence (De Neys, Cromheeke, & Osman, 2011). Bluntly put, although reasoners might be biased, they at least seem to sense that they are erring. In this chapter I present emerging work on the development of this critical conflict or bias sensitivity process. I will try to clarify that the efficiency of the conflict detection process might be a key factor that distinguishes older and younger reasoners. The chapter starts with an overview of the core findings of the conflict detection studies with adults. Next, I review the developmental findings. I conclude the chapter by discussing limitations of the presented developmental framework and sketch directions for further research.

For clarity, the reader might want to note that I will be using the label “correct” or “logical” response as a handy shortcut to refer to “the response that has traditionally been considered as correct or normative according to standard logic or probability theory”. The appropriateness of these traditional norms has sometimes been questioned in the reasoning field (e.g., see Stanovich & West, 2000, for a review). Under this interpretation, the heuristic response should not be labeled as “incorrect” or “biased”. For the sake of simplicity I stick to the traditional labeling. In the same vein, I use the term “logical” as a general header to refer both to standard logic and probability theory.

## CONFLICT DETECTION STUDIES WITH ADULTS

Research on conflict detection during thinking has focused on people’s processing of the infamous classic reasoning tasks that have been studied for decades in the reasoning and decision making field (e.g., base-rate neglect tasks, ratio-bias tasks, conjunction fallacy, belief bias syllogisms, see De Neys, 2012, for examples). Giving the correct response in these tasks requires only the application of some very basic logical or probabilistic principles. However, as the introductory base-rate neglect example illustrated, the tasks are constructed such that they intuitively cue a tempting heuristic response that conflicts with these principles. The basic question that the detection studies have been trying to answer is whether people are sensitive to this conflict and notice that their heuristic response is questionable. Therefore, the studies typically contrast people’s processing of the classic problems with newly constructed control versions. In the control or no-conflict versions the conflict is removed and the cued heuristic response is consistent with the logical response. For example, a no-conflict control version of the introductory base-rate problem would simply switch the base-rates around (i.e., the problem would state that there are 995 woman and 5 men in the sample). Everything else stays the same. Consider this example:

A psychologist wrote thumbnail descriptions of a sample of 1000 participants consisting of 5 men and 995 women. The description below was drawn randomly from the 1000 available descriptions.

Sam is a  25 years old writer who lives in Toronto. Sam likes to shop and spends a lot of money on clothes.

What is most likely?
a. Sam is a woman.
b. Sam is a man.

Hence, both heuristic considerations based on the description and logical ratio considerations cue the exact same response.

In a nutshell, the conflict detection studies have introduced a wide range of subtle processing measures to examine whether people process the conflict and no-conflict versions differently. For example, one basic procedure has been to simply look at people's response latencies: A number of studies reported that people need typically more time to solve the conflict than the control versions (e.g., Bonner & Newell, 2010; De Neys & Glumicic, 2008; Stupple & Ball, 2008; Thompson, Striemer, Reikoff, Gunter, & Campbell, 2003; Villejoubert, 2009). Now, the only difference between the two versions is whether the cued heuristic response is consistent with the correct logical response or not. For example, in the base-rate problem the only modified factor in the control version is the fact that the base-rates were switched around. If biased reasoners were really mere heuristic thinkers who neglected the base-rate information, they should not process the two types of problems any differently. Hence, the latency findings support the idea that people are sensitive to the logical status of their judgment: If people's intuitive heuristic answer conflicts with the logical norm, their problem processing time will increase.

Further support for this claim has come from gaze and eye-tracking studies that showed that the longer latencies are specifically accompanied by a longer inspection of logically critical problem information. For example, Ball, Philips, Wade, and  Quayle (2006) observed that after participants read the conclusion of a conflict syllogism in which the conclusion believability conflicts with its logical validity (e.g., a problem with a valid but unbelievable conclusion) they make saccades to the major and minor premises and start re-inspecting this information. Such "reviewing" was found to be much less pronounced on the no-conflict problems. De Neys and

Glumicic (2008) observed a similar gaze trend with base-rate problems: When solving conflict versions, participants showed an increased tendency to re-view the paragraph with the base-rate information after they had read the personality description.

In a surprise recall test that was presented to participants after the study, De Neys and Glumicic (2008) also observed that the increased base-rate inspection was accompanied by a better recall of the base-rate information for the conflict vs. no-conflict problems. Interestingly, in a subsequent study, De Neys & Franssens (2009) showed that in contrast to the logical information, information that was associated with the heuristic response was less accessible in memory after solving conflict problems. Participants in this study were given a lexical decision task in which they had to decide whether a string of letters formed a word or not after each reasoning problem. Results showed that lexical decisions about words that were linked to the cued heuristic response took longer after solving conflict vs. control problems, suggesting that participants had attempted to block this information during reasoning.

The behavioral conflict findings have also been validated with a brain-based approach. For example, De Neys et al. (2008) used fMRI to monitor the activation of a specific brain area, the anterior cingulate cortex (ACC), which is believed to mediate conflict detection during thinking (e.g., Botvinick, Cohen, & Carter, 2004). Participants were given classic conflict base-rate problems and the no-conflict control versions. In line with the behavioral findings, results showed that the ACC was much more activated when people solved the conflict versions than when they solved the control versions. In a subsequent study, participants' skin-conductance was recorded to monitor autonomic nervous system activation while solving conflict and no-conflict syllogisms (De Neys et al., 2010). Results showed that solving the conflict problems resulted in a clear electrodermal activation spike. Hence, in addition to the ACC activation, solving conflict problems literally aroused participants. These neural conflict signals have also been shown to affect people's subjective response confidence: Participants typically indicate that they feel less confident about their answer after solving conflict problems than after solving the control problems (e.g., De Neys et al., 2011; see also Morsanyi & Handley, 2012, for related findings on people's affective evaluation).

In sum, the conflict detection studies with adults indicate that although people might be often biased and fail to give the correct logical answer on many reasoning tasks, they are not completely oblivious to their bias. Reasoners show some basic sensitivity to the fact that their heuristic answer conflicts with logical considerations. This conflict sensitivity entails that they do not simply disregard the logical implication of their judgments.

## DEVELOPMENTAL CONFLICT DETECTION STUDIES

Numerous authors have argued that for sound reasoning it is paramount that reasoners monitor their heuristic intuitions for conflict with logical principles and subsequently inhibit the tempting heuristics in case such a conflict is detected (Barrouillet, 2011; Evans, 2010; Stanovich & West, 2000; De Neys & Glumicic, 2008). Therefore, the conflict detection findings that I reviewed above have been taken as support for the idea that heuristic bias typically results from an inhibition failure (e.g., Bonner & Newell, 2010; De Neys & Glumicic, 2008). That is, the problem does not seem to be that people do not detect that the heuristic response is questionable and needs to be discarded, but rather that people fail to complete the demanding inhibition process (e.g., De Neys & Franssens, 2009). This idea fits with the vast literature in the reasoning field that has stressed the critical role of inhibitory processing skills to override erroneous heuristic responses (e.g., Brainerd & Reyna, 2001; De Neys & Van Gelder, 2008; Handley et al., 2004; Houdé, 1997, 2007; Moutier, Plagne-Cayeux, Melot, & Houdé, 2006; Simoneau & Markovits, 2003; Stanovich & West, 2000).

However, it is crucial to stress that the bias detection studies have been typically run with adult participants. In general, developmental psychologists have often stressed that reasoning is a multi-component process and that biased responses might have multiple causes (e.g., Brainerd & Reyna, 2001; Jacobs & Klaczynski, 2002; Markovits & Barrouillet, 2004; Stanovich, West, & Toplak, 2011). Hence, it cannot be excluded that bias detection failures play a more crucial role earlier on in our reasoning development. This hypothesis receives some support from basic neurological studies that suggest that the Anterior Cingulate Cortex (ACC), the critical brain structure that is supposed to be mediating elementary conflict monitoring, is quite slow to mature and would only reach full functionally throughout adolescence (e.g., Davies, Segalowitz, & Gavin, 2004; Fitzgerald et al., 2010; Santesso & Segalowitz, 2008). This tentatively indicates that there might be a critical transition with respect to the locus of heuristic bias in human development. That is, whereas adults would be primarily biased because they fail to inhibit the heuristic response after successful conflict detection, younger reasoners could be biased because they fail to detect the need to inhibit the heuristic response in the first place.

Together with a number of colleagues I recently started to explore and test this developmental bias detection hypothesis (e.g., De Neys et al., 2011; De Neys & Feremans, 2012; De Neys, Lubin, & Houdé, 2013; Steegen & De Neys, 2012). I review our initial findings below.

***Adolescents***

Based on the neurological evidence that suggest that the ACC slowly develops throughout adolescence (e.g., Davies et al., 2004; Fitzgerald et al., 2010; Santesso & Segalowitz, 2008), we decided to start our developmental work by contrasting the bias detection efficiency of a group of early adolescents (i.e., 13 year old middle school students) and late adolescents (i.e., 16 year old high school students). In their studies with adults (De Neys et al., 2011, Experiment 1 and 2), De Neys and colleagues already established that the previously documented neural conflict detection signals were also reflected in people's response confidence. Biased participants typically indicated that they felt less confident about their answer after solving conflict problems than after solving the control problems[1]. This directly indicated that participants questioned the correctness of their erroneous response. We decided to use this confidence measure to test the conflict detection efficiency in our first developmental study (De Neys et al., 2011, Experiment 3). Just as in our work with adults, our adolescents were presented with conflict and control versions of classic tasks (e.g., base-rate and conjunction fallacy problems). After answering each problem they were asked to indicate how confident they were that their answer was correct on a scale ranging from zero to 100%.

[1] Not surprisingly, in the rare case that participants answered the conflict problem correctly, the confidence decrease was less clear. That is, adults who give the correct response also seem to know that it is correct.

Reasoning accuracy-wise the results showed that, just like most adults, the vast majority of our two adolescents groups were biased and failed to solve the conflict problems correctly. Further in line with the findings in adult groups, the critical confidence findings established that biased late adolescents also showed the confidence drop (i.e., about 10% decrease) after solving conflict problems. However, consistent with our developmental working hypothesis, this confidence decrease was less clear for biased early adolescents (i.e., about a 5% decrease). Hence, as expected, overall younger adolescents did seem to have a harder time detecting the biased nature of their judgment.

***Pre-adolescents***

Our initial study suggested that conflict detection during reasoning was less efficient for early than for late adolescents. However, although the confidence decrease was statistically smaller for early adolescents, it was not completely absent. In a subsequent study (De Neys & Feremans, 2012) we therefore wanted to validate our initial findings by focusing on even younger age groups. In theory, conflict detection should be even more problematic in the preadolescent age range, of course. Consequently, we decided to contrast the performance of pre-adolescent third graders (i.e., 9 year-olds) and early adolescent sixth graders (i.e., 12 year olds) in our next study.

To make sure that the format of the reasoning task would be suited for the younger children in this study, we decided to adopt the child friendly adaptation of the base-rate task that was introduced by De Neys and Vanderputte (2011). In this task children are familiarized with the base-rates in a sample by showing them cards that depict characters that belong to one of two groups. For example, nine cards might depict a boy and one card might depict a girl. On the back of the cards, children see a picture of an object that will cue a clear stereotypical association. For example, children would be told that on the back we printed a picture of the boy's or girl's favorite toy (e.g., a toy truck or a doll). Next, children observe how the experimenter shuffles the cards, puts them in a bag, and randomly draws one card from the bag. The experimenter always shows children the back side of the drawn card (e.g., a truck) and then asks them whether there will be a boy or girl on the front. By playing around with the base-rates (e.g., nine girls/one boy or nine boys/one girl) one can easily construct conflict and no-conflict control problems. Hence, this format maintains the crucial characteristics of the original base-rate problems while remaining appropriate for testing younger children.

We measured the bias detection sensitivity by asking the children to rate their response confidence on a simplified 4-point rating scale that ranged from 0 (really not sure) to 3 (totally sure). Children were familiarized with the scale and had to put a board game pawn on the number that best reflected their feeling of confidence.

Before presenting the results I would like to highlight an important methodological issue. A critical prerequisite to study conflict detection in a developmental context is of course that all age groups are familiar with the stereotype material. For example, if children have not yet acquired the typical "girls-like-shopping" stereotype, the base-rate problem that I presented in the introduction will simply not cue a heuristic response in younger age groups and there will be no conflict to detect. Although the absence of a cued intuitive response entails that correct responding no longer requires a demanding inhibition process and has been shown to help children reason more accurately (even far more accurately than adults, e.g., see Davidson, 1995; De Neys & Vanderputte, 2011; Jacobs & Potenza, 1991; Reyna & Brainerd, 1994; Stanovich, West, & Toplak, 2011) it is clear that it would confound the assessment of their conflict detection skills. Clearly, any measured absence of conflict detection in younger age groups would not point to a less developed detection skill under these circumstances. Hence, when drawing conclusions about the efficiency of conflict detection across age groups it is paramount to use stereotypes and material that is familiar to all age groups (e.g., see De Neys & Vanderputte, 2011, for an extensive discussion of the role of stereotype knowledge development in reasoning). Consequently, all problem content in our studies was carefully pretested to make sure that it evoked the intended heuristic response.

Results of the study were pretty straightforward. As in our first study, biased early adolescent sixth graders still showed a significantly lower confidence rating after solving conflict vs. control problems. However, this effect was no longer observed in the group of third graders. That is, biased third graders were fully confident that their response was correct and did not show any sensitivity to their errors.

At this point it is probably useful to discuss a second methodological issue when drawing conclusions about the efficiency of children's conflict detection skills. Just as it is important to make sure that the problems cue a heuristic response, one needs to be sure that children have some basic knowledge about the logical principles that are evoked in the tasks. If third graders do not know that base-rates matter for their judgment, for example, the lack of bias awareness should not be attributed to a conflict detection failure but rather to an insufficiently developed logical/probabilistic knowledge base. To eliminate such a confound, the children in our study were also presented with an abstract problem version. In this problem the cards did not depict a character or object but were simply colored yellow or blue. There were nine yellow cards and one blue card. The back side of all cards was white. The experimenter showed the white back side after drawing it from the bag and asked what color the other side would have. Hence, on this abstract problem heuristic thinking could not bias (or help) sound reasoning. Solving the problem relies on mere logical thinking about the group sizes. Thereby the problem allowed us to check whether our youngest reasoners had mastered the necessary logical knowledge about the impact of relative group sizes or base-rates on a probability estimate. Results showed that this was indeed the case. Even our third graders solved the abstract problem almost perfectly[2]. This establishes that our observed lack of confidence decrease in third graders indeed resulted from a failed conflict detection and not from a mere logical knowledge gap.

In sum, taken together our initial studies indicate that conflict or bias detection efficiency in classic reasoning tasks shows critical improvement near the start of adolescence. In contrast with older reasoners, young preadolescents do not yet seem to detect that their heuristic response conflicts with logical principles and biases their judgment. These findings fit with the observation that the brain-structure that is believed to mediate conflict detection (i.e., the ACC) is quite late to mature and only starts to reach proper functionality after the onset of adolescence (e.g., Davies et al., 2004; Fitzgerald et al., 2010; Santesso & Segalowitz, 2008).

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[2] Note that this fits with previous developmental work that established that even infants often show some basic understanding of the logical principles that are evoked in the classic "bias" tasks (e.g., Brainerd & Reyna, 2001; De Neys & Everaerts 2008; Morris, 2000; Téglás, Girotto, Gonzalez, & Bonatti, 2007)

***Cueing detection?: preschoolers and conservation error detection***

Do our findings imply that heuristic bias detection is by definition impossible for pre-adolescent reasoners? Not necessarily. In a third study (De Neys, Lubin, & Houdé, 2013) we showed that under the right circumstances, even preschoolers can show some sensitivity to their judgment bias. I'll first describe the study and then clarify what I mean by "the right circumstances".

In the study we decided to move away from the typical logical and probabilistic reasoning tasks that were used in our previous detection work. We focused on a judgment bias in a different domain, namely number conservation. Number conservation refers to the insight that a numerical quantity will remain the same despite adjustment of its apparent shape or size. Imagine you are presented with a row of coins that is subsequently being stretched out. Adults and older children will have little trouble grasping that although the stretching makes the row longer, it does not increase the number of coins, of course. However, until approximately age seven children typically fail this task and seem to be convinced that the longer row also contains more coins (e.g., Piaget, 1941/1952; see also Borst et al., in press; Houdé, 1997; Ping & Goldin-Meadow, 2008). That is, in the coin spreading task children tend to be biased by an erroneous intuition that is visuospatial in nature (i.e., a so-called 'length-equals-number' intuition).

The goal of the study was to explore young children's possible sensitivity to their number conservation errors. To test our hypothesis we used a method similar to the one we used in the initial bias detection studies with the base-rate problems. Children were given both a classic version of the number conservation task in which the intuitively cued visuospatial length-equals-number response conflicted with the correct conservation response (i.e., conflict version) and a control or no-conflict version in which this conflict was not present. That is, in the conflict version children initially saw two rows of equal length containing the same number of coins. Next, one of the rows was spread apart so that one is longer than the other and children were asked whether the two rows contained the same number of coins. In the no-conflict version the two rows also have the same number of coins but initially differed in length. The longer row is now transformed (i.e., contracted) to give both rows equal length and the child is asked whether the two rows contain an equal number of coins. Hence, the critical difference is that the control problem does not cue an erroneous visuospatial response.

After solving each version children were asked to indicate their response confidence on a rating scale. Just as in our studies with adolescents and pre-adolescents this allowed us to measure participants' bias detection sensitivity. We focused on the performance of preschoolers since older children (e.g., +7 years) have little trouble in answering the conservation task correctly. Obviously, there is little point in studying bias sensitivity if one's judgment is no longer biased.

Results showed that, as expected, the vast majority of our preschoolers failed to solve the conservation task and responded that the longer row also contained more coins. However, similar to older reasoners in our conflict detection work with logical and probabilistic reasoning tasks, preschoolers seemed to detect the erroneous nature of their judgment. Biased (i.e., so – called "non-conserving") preschoolers were significantly less confident about their response on the conflict than on the no-conflict problem. Hence, although our preschoolers did not manage to give the correct conservation response, their confidence indicated that they were not completely oblivious to their error.

To recap, our initial developmental studies suggested that bias detection during logical and probabilistic reasoning is only observed after the onset of adolescence (i.e., by the end of elementary school, e.g., De Neys et al., 2011; De Neys & Feremans, 2012). We linked this developmental pattern to the late maturation of the Anterior Cingulate Cortex (ACC, e.g., Davies et al., 2004; De Neys et al., 2008; Fitzgerald et al., 2010). Given these findings, the successful number conservation error detection at the preschool age might seem somewhat surprising. However, here on needs to take into account that a less developed ACC (i.e., a less efficient detection engine) does not imply a lack of all conflict detection. Indeed, basic error monitoring studies have shown that even three year-olds can detect errors in simple tasks that do not cue a strong intuitive response (Lyons & Ghetti, 2011). Arguably, in comparison with logical and probabilistic reasoning tasks in which the cued intuitive response typically entails a semantic prior belief or stereotypical information, the critical physical transformation in conservation tasks might act as a cue that directs children's attention and thereby facilitates monitoring.

Hence, detection of intuitive bias in number conservation might be less demanding and occur at a younger age than in logical and probabilistic reasoning tasks.

Note that the idea that monitoring or conflict detection demands can be facilitated receives some support from our previous work with logical and probabilistic reasoning tasks. Here we need to highlight that the conflict factor in these studies was typically manipulated within-subjects. That is, the same participant is presented with multiple conflict and no-conflict problems. Kahneman (2002) has since long argued that such within-subject tests are less demanding because they help to focus people's attention on the conflict. Bluntly put, after a couple of trials people will get the hang of it and notice that they need to pay attention to potential conflict. Hence, the purest (or hardest) test of people's conflict detection capacity concerns the first problems in the series[3]. In our studies with adults and late adolescents we found that the detection effects were indeed present right from the start (e.g., De Neys & Franssens, 2009; De Neys & Glumicic, 2008; De Neys et al., 2010, 2011). Hence, for our older reasoners the observed detection effects did not result from a cueing effect. However, this was no longer the case for our young adolescents. Although they showed a confidence decrease near the end of the experiment, this decreased confidence was not observed on the initial trials (De Neys et al, 2011, Experiment 3). Hence, in line with Kahneman's (2002) claims, attentional cuing resulting from repeated testing does seem to facilitate conflict detection for younger reasoners.

In general, these findings support the idea that task-related attentional cues can boost bias detection in younger age groups. This points to a number of interesting implications. First, the fact that conflict detection can be improved by attentional cues sketches an interesting avenue for future research. Indeed, future studies that directly test which features (e.g., warnings, presentation of multiple problems, highlighting certain content, etc.) do or don't facilitate the detection of conflict between intuitive heuristics and logical knowledge seem specifically promising. At an applied level, this can help to design effective intervention

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[3] More specifically, a between-subject test in which only the first problem that people are presented (e.g., half the sample solves a conflict version first and the other half a no-conflict version) is taken into account.

programs to improve young reasoners thinking despite their intrinsically more limited detection capacities. Second, at a more theoretical level it also indicates that when making general statements about children's bias detection efficiency it is important to keep in mind that these can be modulated and might differ across domains depending on the task demands. Third, in and by itself, the finding that preschoolers show conservation error sensitivity has also direct implications for work on conservation development. For example, in the classic work of Piaget (1941/1952), who introduced the coin-spreading-task, number conservation marked a critical transition from a pre-operational to operational stage in children's thinking. According to Piaget, young children before the age of seven show a structural conservation knowledge deficit. Piaget basically claimed that the young child cannot grasp the conservation principle because it is limited to a purely intuitive and perceptual way of processing information. Our confidence data directly argues against Piaget's classic characterization of the preschool child as an illogical reasoner who is bound to rely on mere visuospatial intuitions. If biased non-conservers would not have some elementary understanding of the conservation principle they should have no reason to doubt their answer. In line with other critiques of Piaget's claim (e.g., Bjorklund & Harnishfeger, 1990; Borst et al., in press; Dempster & Brainerd, 1995; Houdé, 2000; Houdé & Guichart, 2001; Leroux et al., 2006; Poirel et al., in press) this indicates that preschoolers are more knowledgeable than their conservation errors suggest.

***Adolescents and inhibition initiation***

Our conflict detection study with adolescents indicated that late adolescents showed a bias sensitivity that was comparable to the levels we observed in adults. It is important to stress that this does not necessarily imply that the way that reasoners deal with heuristic bias and conflict shows no further evolution in young adulthood. As I noted in the overview of the adult findings, it has been observed that after detecting conflict, adults also engage in an inhibition process and at least try to discard the erroneous heuristic response (e.g., De Neys & Franssens, 2009). To recap, adults in De Neys and Franssens' study were given a lexical decision task in which they had to decide whether a string of letters formed a word or not after each reasoning problem. Results showed that lexical decisions about words that were linked to the cued heuristic response (e.g., with the introductory base-rate problem these could be the words "purse" or "skirt") took longer after solving conflict vs. control problems. Hence, information that was associated with the heuristic response was less accessible in memory after solving conflict problems. This suggested that participants had attempted to inhibit this information during reasoning.

Steegen and De Neys (2012) recently ran a similar study with adolescents. We observed that adolescents who gave the correct response on conflict problems also showed the impaired access (i.e., longer decision times) to target words that were associated with the cued heuristic response. Not surprisingly, this indicates that sounds reasoning in younger reasoners also relies on an inhibition of the heuristic response (see also Moutier et al., 2006, for related evidence). However, unlike the findings with adults, we did not observe this memory impairment for biased late (or younger) adolescents. Our initial conflict detection studies showed that at least late adolescents are very good at bias detection. However, the Steegen and De Neys study suggests that unlike in biased adults, this successful bias detection is not yet followed by an inhibition engagement in adolescents. It is well established that inhibitory processing capacity increases from childhood to young adulthood (e.g., Bedart et al., 2002; Christ, White, Mandernach, & Keys, 2001; Dempster & Brainerd, 1995; De Neys & Everaerts, 2008; De Neys & Van Gelder, 2008; Houdé, 2007; Klaczynski & Narashimham, 1998; Kokis, Macpherson, Toplak, West, & Stanovich, 2002). Biased late adolescents' lack of inhibition engagement, despite successful conflict detection, might indicate that the additional inhibition engagement step is still too demanding for them.

## CLARIFICATIONS AND FUTURE DIRECTIONS

I this last section I would like to clarify some possible misconceptions and sketch directions for future research.

### *Need for generalization*

In this chapter I presented emerging work on the development of conflict or bias detection during thinking. I hope to have clarified that this is an important process that deserves further attention from developmental scientists. However, it will be clear that the framework that I presented here is still in its infancy and will need to be further developed and validated. For example, it will be critical to test the generalizability of the findings across different tasks. In the section on detection cuing I already noted the importance of generalizing the findings across different domains (e.g., conservation vs. logical and probabilistic reasoning). However, it is important to bear in mind that even within the domains of reasoning and decision making, our developmental studies have so far only focused on one specific task (e.g., base-rate neglect tasks). One strong point of the conflict detection work with adults is precisely that the findings have been validated with a wide range of tasks (e.g., base-rate neglect, e.g., De Neys & Glumicic, 2008; syllogisms, e.g., De Neys et al., 2010, De Neys & Franssens, 2009; conjunction fallacy, e.g., De Neys et al., 2011, Villejoubert, 2009; ratio-bias, e.g., Bonner & Newell, 2010; bat-and-ball problem, e.g., De Neys, Rossi, & Houdé, 2013). This establishes that the findings with adults are not driven by one or the other specific tasks confound or characteristic (e.g., Klauer & Singmann, 2012; Pennycook, Fugelsang, & Koehler, 2012). Future developmental studies will need to take this task generalization seriously. In addition, a second limitation that needs to be taken into account is that our developmental studies have focused on one specific (behavioral) detection measure (i.e., confidence ratings). Again, the conflict detection studies with adults have used a wide-range of methods and techniques to measure detection sensitivity (e.g., latencies, e.g., Bonner & Newell, 2010, De Neys & Glumicic, 2008; eye-tracking, e.g., Ball et al., 2006; memory recall, e.g., Franssens & De Neys, 2009; skin-conductance, e.g., De Neys et al., 2010; EEG, e.g., De Neys, Novitskiy, Ramautar, & Wagemans, 2010; fMRI, e.g., De Neys et al., 2008). In addition to task generalization such future method generalization is also critical. Note that a developmental neuroscientific approach would be especially welcome. Indeed, we have hypothesized that our initial findings pointing to the less efficient bias detection for younger reasoners can be linked to the late maturization of the Anterior Cingulate Cortex. In this respect it would be very interesting to start running fMRI, EEG, or skin-conductance studies to test directly whether the lack of a confidence drop is accompanied by a less responsive ACC in younger age groups.

In sum, I believe that the emerging framework that I sketched in this chapter is promising "work-in-progress". However, the young nature of the research definitely entails that the initial findings and claims need to be interpreted with some caution.

***What do we "know": Implicit bias detection***

It is perhaps also useful to stress that the conflict detection studies with adults have typically characterized the documented bias detection as an implicit process (e.g., De Neys, 2012). That is, the claim that adults know that they are biased and detect logical violations does not entail that they have a fully explicit understanding of the violated principles that they can verbally justify. A key point is that the necessary logical knowledge that allows people to detect a conflict with the cued heuristic response is conceived to be implicit in nature. Consequently, the conflict experience has been described as a "gut feeling" (e.g., Franssens & De Neys, 2009; Thompson, 2009; Thompson, Prowse Turner, & Pennycook, G., 2011): People will be aware *that* there is something fishy about their heuristic response, but they will not be able to put their finger on it and explain *why* their response is questionable. More precisely, the idea is that the conflict between implicitly activated logical knowledge and the cued heuristic response creates arousal. People experience this arousal, this makes them doubt their heuristic response, but they will not be able to justify why their response is questionable. However, the key point is that the implicit knowledge at least suffices to signal that the heuristic response is not fully warranted.

The interested reader can find a detailed discussion of this issue elsewhere (see De Neys, 2012) but I would simply like to stress here that the detection in younger reasoners that I reviewed and documented in this chapter needs to be conceived at the same level. Obviously, our detection findings do not entail that young adolescents (or non-conserving preschoolers for that matter) have a fully explicit understanding of the logical principles they sense to be violating.

## IN CLOSING

Some ten years ago, guest editors Henry Markovits and Pierre Barrouillet (2004) noted in a special developmental issue of the journal Thinking and Reasoning that although reasoning and decision-making were once one of the prime research areas for developmental scientists, interest had faded in more recent years. Markovits and Barrouillet suggested that one of the reasons for this decline was the rise of the "Heuristics and Biases" research program and its demonstration of the widespread bias in human reasoning. This massive bias seemed to point to a developmental standstill in human reasoning. That is, if even the vast majority of educated university students fail to solve basic logical reasoning problems, one might easily get the impression that there doesn't seem to be a lot of development going on. Consequently, as Markovits and Barrouillet put it, many developmental scientists concluded that "there is no point in looking at the development of something that is not present".

I mention Markovits and Barrouillet's special issue here because it actually kick started my interest in reasoning development. Bluntly put, I guess that some 10 years later I am also in a position to start sketching a way out of the apparent deadlock they mentioned. Looking closely at the conflict detection process suggests that the lack of reasoning development is more apparent than real. Although both adults and younger reasoners are indeed biased most of the time, the findings that I reviewed here indicate that older reasoners at least detect that their responses are biased. Consistent with recent insights in the developmental field (e.g., Brainerd, Reyna, & Ceci, 2008; Klaczynski, Byrnes, & Jacobs, 2001; Reyna & Farley, 2006; Reyna et al., 2003) this differential bias awareness argues against the idea of a developmental standstill in human reasoning.

As I stated above, I fully realize that this framework needs to be further validated and caution is needed when interpreting the initial findings. However, I do hope I managed to illustrate that studying the development of conflict detection during thinking holds great promise and deserves to attract more interest from developmental psychologists.

## ACKNOWLEDGEMENTS

Parts of this chapter are based on a more condensed previous paper that was published in Child Development Perspectives (De Neys, 2013). Preparation of this manuscript was supported by a grant from the Agence National de la Recherche (ANR-12-xxxx-000).

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