

THE DEVELOPMENT OF COUNTERFACTUAL REASONING IN BELIEF REVISION

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The present study examines how children revise beliefs in the face of a new piece of information that they must accept as true and under what circumstances their belief-revision processes differ from college-aged adults. Results suggest that overall, 7-year-old children (children at Stage 2 reasoning; Moshman, 1990) revise beliefs as do adults, by rejecting particular beliefs in favour of more general ones. However, only adults adjust their revision strategy as a consequence of the logical structure of the initial belief set. Adults, but not children, tend to organise their revised beliefs to be consistent with general statements more often when the set of beliefs create a Modus Tollens logic structure than when they create a Modus Ponens structure. This difference in belief revision by the two age groups reflects their sensitivity to logical structure.

Introduction

A typical child, as well as an adult, spends a considerable portion of her early life adding and revising hypotheses and beliefs about the way the world works (e.g., Karmiloff-Smith & Inhelder, 1974). One way to understand this fundamental belief revision process is to view it as the action of a set of mechanisms embodied in counterfactual reasoning. This type of inference occurs when the individual is compelled to treat the new, disbelieved piece of information as “true”, even though it disrupts the existing set of beliefs (Chisholm, 1946; Rescher, 1964). There is ample evidence that adults are skilled at belief-revision and reasoning from false assumptions (e.g., Dieussaert, Schaeken, & d’Ydewalle, 2002; Revlin, Cate, & Rouss, 2001). Children, the precursors to adults, appear to follow counterfactual reasoning in their pretend play (e.g., Nichols & Stich, 2000), but are other aspects of their counterfactual thinking processes similar in other ways to adults? The present study examines this question using a paradigm employed in adult research of belief revision.

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The majority of studies suggest that counterfactual reasoning starts to develop early in life, around 3-4 years of age. Pretence, an ability which develops around 2 years of age, seems to be its precursor (e.g., Amsel & Smalley, 2000; Ferrell, 2005). Pretence begins, like counterfactual reasoning, with an initial premise that is false in reality (e.g., "This box is a spaceship"). Around the age of 3-4, children are able to produce and to reason from different types of counterfactuals spontaneously (e.g., Beck, Robinson, Carroll, & Apperly, 2006; O'Brien, Dias, Roazzi, & Braine, 1998). Guajardo and Turley-Ames (2004) showed that children from the age of 3 can generate an alternative antecedent in response to a counterfactual outcome after hearing a story (counterfactual antecedent tasks), and vice versa for counterfactual consequent tasks. Their performance on these tasks increased between the age of 3 and 5. More specific, their ability to generate upward (better than reality; e.g., "If had paid more attention to the road, I would have avoided the collision"), downward (worse than reality; e.g., "If I had listened to her, I would have made the wrong assignment"), and additive counterfactuals (addition of action; e.g., "If I had grounded her, would her behaviour have improved?") increased with age; but the generation of subtractive counterfactuals (removal of action; e.g., "If I had not grounded her, would she have learned her lesson?") improved less. Like adults, children generate fewer subtractive than additive counterfactuals in part because subtractive counterfactuals require more cognitive resources than other counterfactuals (Turley-Ames & Whitfield, as cited in Guajardo & Turley-Ames, 2004). In addition, Beck, Riggs, and Gorniak (2009) found that counterfactual reasoning is related to inhibitory control (executive function) – children before the age of 5 have difficulty separating real-world knowledge from fantasy, and are unable to ignore their real world knowledge (Beck et al., 2006) unless fantasy instructions are provided (e.g., Harris & Leever, 2000; Markovits & Vachon, 1989). Rafetseder, Cristi-Vargas, and Perner (2010) showed that only from the age of 5 or 6 children will start to reason counterfactually as adults do by creating a counterfactual world that is not constrained by actual events (in line with David Lewis' nearest possible world, see later). By the time people reach adulthood, counterfactual reasoning forms the basis of belief-revisioning (e.g., Dawes, 1964; Revlin, Bromage, & Van Ness, 1981; Stalnaker, 1998). Although belief revisioning has been studied among adults from different perspectives (e.g., Dieussaert, Schaeken, De Neys, & d'Ydewalle, 2000; Elio & Pelletier, 1997; Hadjichristidis, Handley, Sloman, Evans, Over, & Stevenson, 2007; Markovits & Schmeltzer, 2007; Politzer & Carles, 2001), little is known about the transition between the child's process of counterfactual reasoning and the adult form of belief revisioning. How do people normally absorb facts that conflict with their enduring beliefs and how do children adapt to this kind of situation? Should adult reasoning

processes be modelled as structurally different from the child's or do they both rely on the same basic processes?

The purpose of the present study is to examine the development of counterfactual reasoning in belief revision by comparing the performance of children and adults on the same inference task. Although the two populations of ages do not exhaust the developmental continuum, they do allow us to identify any meaningful difference at the extremes of the continuum. We do this by employing a task domain called belief-contravening problems (Rescher, 1964) and by using an adjusted visual presentation procedure created by Revlin, Calvillo, and Ballard (2005) to study adult reasoning. The present study is not directed towards elaborating on children's causal reasoning about preconditions for events (e.g., Harris, German, & Mills, 1996), rather it addresses the questions of how children revise their beliefs and whether there are commonalities between children's non-causal counterfactual reasoning and that of adults.

Belief revision paradigm

One paradigm for studying how people revise their beliefs is based on the treatment in the philosophy of science where Rescher (1964; 2007) proposed belief-contravening problems as a model for belief revision. In these problems, our knowledge is represented as a set of believed propositions. We are then confronted by counterfactual assumption that creates an inconsistency in this set of accepted beliefs. The counterfactual assumption has to be reconciled with the beliefs, by retaining some and rejecting others. An example of such a problem is illustrated in (1), where information about Knights and their hats are previously conveyed in a story.

- (1) (a) All good knights of King William wear a white hat. (general premise, $p \rightarrow q$)
 (b) This knight here wears a black hat. (particular premise, $\sim q$)
 (c) This knight works for King Igor. ($\sim p$)
 Let's pretend that ...
 (d) This knight works for King William. (counterfactual premise, p)

After certifying the consistency of the three premises (a – c), the reasoner is asked to entertain a fourth, counterfactual, assumption (d) that introduces an inconsistency into the set of beliefs that requires the beliefs to be revised. To accomplish this, statement (c) must be rejected because it directly contradicts the counterfactual assumption. This leaves statements (a) and (b). If the assumption is combined with (a), the two jointly contradict statement (b). If the assumption is combined with (b), the two jointly contradict statement (a). Clearly, (a) and (b) cannot both be correct. Therefore, the reasoner must reject

either statement (a) or statement (b) to maintain as many beliefs as possible. Situations such as in (1) are called *Modus Tollens (MT) problems* (Byrne & Walsh, 2005) because prior to the counterfactual assumption the belief set is logically arranged as an MT structure. Note that the phrase, "Let's pretend" invites the reasoner to engage in counterfactual reasoning.

When the statements in (1) are arranged in a different logical form, they are called *Modus Ponens (MP) problems*, as shown in (2).

(2) (a) All good knights of King William wear a white hat. (general premise, $p \rightarrow q$)

(b) This knight works for King William. (particular premise, p)

(c) This knight wears a white hat. (q)

Let's pretend that ...

(d) this knight wears a black hat. (counterfactual premise, $\sim q$)

To resolve the inconsistency created by the counterfactual premise in (1) and (2), either the general or the particular premise has to be revised. Retaining the general premise (a) and reject the particular premise (b) is called the *generalist solution* (after Revlis, 1974). In contrast, retaining the particular premise (b) and rejecting the general premise (a) is called the *particularist solution*.

There are no simple deductive rules that prescribe how to reason from counterfactual assumptions (e.g., Chisholm, 1946). Logically, both the generalist and the particularist solutions are equally correct. Nonetheless, in paper-and-pencil versions of these belief contravening problems (where problems looked just as those above and are presented in a booklet format) college students reliably prefer the generalist solution (Revlin et al., 2005; Revlin, Calvillo, & Mautone 2003; Revlin et al., 2001; Revlis, 1974; Revlis & Hayes, 1972). Their generalist preference is more pronounced for MT than for MP problems (Revlin et al., 2003; 2001). Elderly participants (average age 70) show this same reasoning pattern; however their tendency to select the generalist strategy is negatively correlated with age (after age 55; Revlin et al., 2003), which could be related to a decline in counterfactual reasoning capacity (e.g., McNamara, Durso, Brown, & Lynch, 2003). These results confirm that the structure of belief revision problems has an influence on adults' reasoning strategy. They also suggest that age, and its related ability to reason counterfactually, has an impact on the way we revise our beliefs.

In the present study, all beliefs are generated from a coherent narrative read to the children. The source of the beliefs has an effect on the reasoners' commitment to them (Dieussaert et al., 2000; Politzer & Carles, 2001). Adults show no reliable preference for retaining general statements when the substance of the problems is arbitrary and devoid of *a priori* believability (Byrne & Walsh, 2005; Elio & Pelletier, 1997; Revlis & Hayes, 1972). However,

when propositions are integrated in a narrative structure, students treat them in the same way as real, law-like beliefs, and of natural semantic categories (Revlin *et al.*, 2005). Markovits and Schmeltzer (2007) confirm that when a conditional belief is embedded in a coherence framework – a belief system of consistent relations – the tendency to revise this belief when faced with contradictory evidence decreases substantially.

It is easy to see the relationship between the belief-contravening paradigm and real-life belief revisioning when people are confronted with a counterexample to a stereotype. Take for example the situation in (3):

(3a) All members of ethnic group A are lazy.

(3b) Hank is lazy.

(3c) Hank is a member of ethnic group A.

(3d) Assume that Hank does something that shows energy and initiative.

In this example, you are forced to consider that (3b) is false and that (3a) and (3c) cannot both be true. Which one should be retained and which should be discarded? Studies of stereotype change (e.g., Hewstone, 1994) would predict that Hank, one atypical member, would be assigned to a subcategory (subtyping) and that the stereotype (3a) would stay intact. In the present study we consider what children and adults do in the face of the counterfactual assumption when they are asked to reason about beliefs that they have acquired from a story.

Dual-space view of belief revision: adults and children

Adult counterfactual reasoning

Which cognitive processes operate when people revise their beliefs due to counterfactual information? Revlin and his colleagues (2003) formulate a promising answer to this question. It is based on David Lewis' proposal of *Possible Worlds* (1973; 1986) and applies three of his principles on counterfactual reasoning to the belief revision paradigm. *Principle 1* states that, when confronted with an assumption that counters our belief system, reasoners select a Possible World in which this assumption is true. In this Possible World inferences then can be made from the counterfactual assumption. This proposal is equivalent to the treatment of children's pretence by Nichols and Stich (2000) in which they state that children create a fantasy world within the constraints of a Possible World Box (a temporary cognitive storage place for the mental representations of a pretended content). *Principle 2* says that reasoners do not select just any Possible World, but one that is closest to the present world ('nearest possible world'). The information, assumptions and inferences added to the possible world, are restricted so that the Possible

World is as similar to the real world as feasible. Nichols and Stich (2000) state that a pretender has the desire to behave in a way that is similar to the way one would behave in reality and that the same inference mechanisms work in the Belief Box (a special cognitive storage place for our beliefs) as in the Possible World Box. *Principle 3* is the *Principle of Modality*. Just as in the real world, statements (premises, beliefs, etc.) in the Possible World can be arranged in terms of degrees of necessity using a modal logic (formalised by Lewis & Langford, 1932; dating back to Aristotle), where generalities are considered to have a higher degree of necessity (more law-like) than particularities.

These three principles of Lewis are the basis for a successful model of belief revision offered by Revlin et al. (2001). It asserts that reasoners will retain the statement with the highest degrees of necessity and reject any inconsistent statement with a lower modal status. Therefore, when confronted with a counterfactual assumption as in the MT problem above, the general premise will be preserved and the particular premise rejected. In the case of MP problems, however, the counterfactual assumption directly contradicts the generality, which reduces its modal status (degree of necessity), and causes it to be treated by the reasoner as an accidental, arbitrary generalisation (Goodman, 1947; Revlis & Hayes, 1972; Ryle, 1949) – more equivalent to the particular statement. Therefore, reasoners show less of a preference for the generalist solution in MP problems.

Children's counterfactual reasoning

The Possible Worlds modal logic model of belief-revisioning has not previously been applied to account for children's reasoning. We know however that children 5 years and older possess some of the critical elements necessary for the model's functioning (e.g., Moshman, 1990). Siegler (1976) demonstrated that children of at least age 5 are capable of identifying necessary events in creating a causal structure (see also Miller, Custer, & Nassau, 2000). We know too that children of this age are capable of understanding the deductive consequences of an assumption (e.g., O'Brien et al., 1998) and can identify logical inconsistencies. In addition, research on probabilistic reasoning about uncertain events confirms that children, from the age of 5, are able to integrate new information into prior information (Giroto & Gonzalez, 2008) and can assemble a coherent causal structure. Hence, children of at least 5 years of age possess the necessary components for counterfactual reasoning described here. It remains to be determined whether they can assemble these cognitive components to draw counterfactual inferences in belief-contravening context, which we hope to answer in this study. The idea put forward by Rafetseder et al. (2010) that children from the age of 5 or 6 start to reason counterfactually as adults do by creating a counterfactual world that is not constrained by actual events, supports the hypothesis that these children will

be able to solve belief-contravening problems. However we cannot make any predictions yet about the revision strategy they will apply – that is, will they follow the Possible Worlds model's process.

Preliminary study

To address our research questions, we first performed an extensive pilot study with 5-, 6- and 7-year-old children. In this pilot study we used a concrete-visual task developed by Revlin *et al.* (2005) that did not require the children to read. Each child heard two fantasy stories that created a coherent belief structure. One narrative (two kingdoms with battling knights) was expressed as an MT problem, the other (a confrontation in a Wild West town between raiders and settlers/heroes) with an MP problem. After hearing a story, the children were confronted with a diorama and a figurine, respectively portraying two locales and a character from the narrative. The participants then heard three story-based statements (equivalent to a, b, and c, above: “*All of King William's knights have white hats; This knight wears a black hat; This knight works for King Igor*”) and had to confirm the consistency of these statements with the diorama and the narrative. Next, the experimenter asked the children to pretend that a counterfactual assumption was true, “*Let's pretend that this knight works for King William*”, which is equivalent to statement (d), above. Subsequently the children were to decide if they wanted to change the figurine (give him a white hat) or to leave it as it was. If a change was made, it was considered as a choice made for the generalist solution, if not it was taken as evidence for the particularist solution.

In this preliminary study, children, were able to solve belief-contravening problems and showed a preference for the generalist solution, equally in MT and MP tasks, similar to adults with the same materials (e.g., Revlin *et al.*, 2005) as shown in Table 1.

Table 1

Percentages of Generalist Solution-choices in the pilot study (corrected for memory and comprehension) compared to the results from Revlin et al. (2005) using the same visual presentation procedure

Pilot study	Modus Tollens		Modus Ponens	
	%	SD	%	SD
Age 5	79*	.42	94 *	.25
Age 6	91*	.29	93*	.26
Age 7	81*	.40	85*	.37
Revlin <i>et al.</i> (2005)	81**	.08	79**	.12

* differ significantly from chance (50%), $\chi^2(1)$, $p < .01$

** differ significantly from chance (50%), $\chi^2(1)$, $p < .05$

It seems that when children – as well as adults – are forced to entertain belief-contravening assumptions about objects, they readily relinquish the truth of what they see in favour of an organised abstraction (Revlin et al., 2005, p. 13).

One limitation of the figurine task is the single-action choice format, changing or not changing the figurine. This is especially problematic for children: Nichols and Stich (2000) state that an important difference between imagining and pretending is the pretender's *desire to behave*, in a way that is similar to the way some character or object behaves in a real world. Behaving in this procedure is 'changing the figurine'. Luria (1961) and Vygotsky (1962) showed that children have more difficulty inhibiting a response (not changing the figurine) than initiating one. In light of the inhibition of a certain action, Strommen (1973, p. 852) states that "the capacity for self-regulation in simple, repetitive situations may be evident by age 5, but it may nonetheless be unrealistic to expect consistent self-regulation in more demanding situations until age 7 or older". In addition, as mentioned earlier, children's counterfactual reasoning performance can be predicted by their inhibitory control (Beck et al., 2009). As such, the generalist solution may have an advantage over the particularist solution in the current procedure.

To address these issues with the current concrete task, we adjusted the task into a full pictorial, dual-action choice format that creates an environment similar to the traditional paper-and-pencil task without the demands of reading for the child. In this task, the participant must choose between pictures that correspond to statements (a) and (b) in the problems above. As such it makes direct contact with the adult methodology (paper-pencil booklet tasks) in ways that other studies (e.g., Amsel, Triofini, & Campbell, 2005) do not, which allows a direct comparison between children's and adults' reasoning.

In Experiment 1 we study the belief revisioning strategies of children by using the improved visual design. Although some researchers claim that children begin to reason counterfactually around the age of 5-6, we wanted to include those students who would be more likely to be able to complete the task. Since in the pilot study, fewer 7-year-old participants were removed from analysis after correction for memory and comprehension of the main elements of the story and the task, the youngest participants in Experiment 1 were primarily 7 years old. A direct comparison with adult reasoners on the same task is undertaken in Experiment 2.

Experiment 1

We have seen in the preliminary study that children and adults show similar belief-revision preferences when the propositions of belief concern objects

that are physically present. The present experiment asks whether children will show a similar reasoning strategy when the believed statements are represented as abstract drawings – equivalent to the paper-and-pencil paradigm typical of the adult research.

Experiment 1 introduces a modified visual task to increase the similarity with the original paper-and-pencil task (e.g., Dieussaert *et al.*, 2000) and to address the issues with the original concrete task (Revlin *et al.*, 2005). An important alteration is the replacement of the diorama and figurines by pictures. Each premise (pre-assumption belief and counterfactual assumption) and each solution is visually represented by a picture. Another key alteration is changing the task into a dual-action choice format. Participants have to execute an action for each solution (replace one of two pictures). We expect that these procedures will result in a response profile similar to the paper-and-pencil task and as such, participants will show a decrease in the use of the generalist strategy for MP problems if they reason in a similar way as adults.

Method

Participants

The participants were thirty children (17 girls, 13 boys), all of whom spoke Dutch as their native language – mean age 6 years 11 months (6; 11), $SD = 0;4$, range 6; 5-8;0. Details about children's ethnic and socioeconomic background were not obtained. The school and the parents gave their permission based on an informed consent.

Materials

The two stories from Revlin *et al.* (2005, Experiment 2), slightly adjusted to children and translated into Dutch, were used in this experiment and are shown in Appendix A and B (translated back into English from the Dutch). Both narratives were presented orally and also portrayed in pictures. Each set of picture represented a pre-assumption condition, a counterfactual assumption and two possible solutions (see Figure 1).

Design

The independent variable was Type of belief contravening problem (two levels, within subjects: MT- and MP-condition). The dependent variable was the Type of solution strategy (general or particular solution). The general premise always expressed a positive property-relation. The order of the two conditions and the order of appearance of the two types of solution were counterbalanced and each participant was run in separate sessions.

Procedure

Each child was tested individually, in a quiet room of the school. A modified version of Revlin et al.'s concrete procedure (2005, Experiment 2) was used. All children received two tasks (MT- and MP-condition). Each task started with a narrative. After hearing the whole story the children were asked to summarise what they had heard (memory-question, see Appendix A & B). If they could not remember the names of the different characters and/or the respective colours of the hats these characters wore, the missing information was stated. Second, the three premises were presented one by one. Each premise was supported by a picture that was placed in front of the participants (see Figure 1). After this, the counterfactual assumption was given ("Let's pretend that ...") and the related picture was placed on top of the picture that directly contradicted it. As a result, the logical consistency of the statements was now in question. To assure that the children understood the implications of the counterfactual assumption, the children had to explain why the story was no longer correct (check-question 1, see Appendix A & B). If they could not do so, the experimenter repeated the first two premises and mentioned that the *pretend* premise runs counter to these two. Two options were offered as a solution for the counterfactual problem. One option represented the generalist solution (e.g., "Either we give this knight a white hat ..."), while the other option represented the particularist solution (e.g., "..., or the knights of King William can also wear a black hat now"). These options were also visually supported (see Figure 1). Each *solution* picture was placed alternately on the rejected picture and was described orally. Afterwards the solution picture was placed above the rejected picture. When the children heard both solutions (and both pictures were placed above the other pictures) they were asked to make a choice. The experimenter emphasised that both options were correct, but that the children had to choose the option that they preferred ("Both of these options are correct, but which one do you find the best?") and that they had to place the selected picture on top of the rejected picture. To verify if the children understood the implication of their action, they were asked to explain why the story was correct again (check-question 2, see Appendix A & B).

Results

Children, who gave an entirely incorrect answer on a check-question ($n_{MT} = 2$, $n_{MP} = 1$) shown in Appendix A and B or gave no answer on both check-questions ($n_{MT} = 1$, $n_{MP} = 1$) were removed from analysis of the corresponding condition. One child failed to follow the instructions and was therefore also removed from all analysis. Hence, in the MT condition 87% (26/30) of the children and in the MP condition 90% (27/30) were included in the analysis.

Narrative

(Modus Tollens condition)

All good knights of King William wear a white hat.

This knight here wears a black hat.

This knight works for King Igor.

Let's pretend that this knight works for King William.

Some of King William's knights wear black hats .

(or)

This knight has a white hat

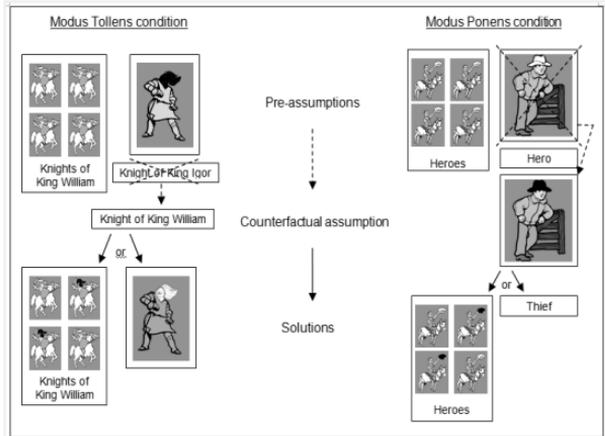


Figure 1

Schematic presentation of procedure in Experiment 1 & 2

Table 2 shows that 88% of the time, 7-year-old children preferred the generalist solution in the MT condition, which differs significantly from chance level (chance was 50% since there were two response options; $\chi^2(1) = 15.385, p < .001$). Seventy per cent of the 7-year-olds also preferred the generalist solution in the MP condition; which also differs significantly from chance level ($\chi^2(1) = 4.481, p < .05$). In spite of the apparent differences in the two conditions, overall, the Wilcoxon matched-pairs Signed Ranks Test showed that children did not follow the generalist path reliable more in the MT condition than in the MP condition ($N_{\text{of non-ties}} = 7, z = -1.13, ns, SR$).

Discussion

Experiment 1 examines if children are able to solve belief-contravening problems and what kind of strategy they apply in solving these problems. We do this by using a visual procedure, improved after an extensive pilot study, which increases the similarity with the original paper-and-pencil task and addresses the issues with the original visual task from Revlin et al. (2005).

Results show that seven-year-old children are able to reason counterfactually in belief-contravening problems and that they prefer to revise a particular statement in favour of the more general one in both MT and MP problems. Although, the preference for the generalist solution decreased 18% for MT problems, this does not reach conventional levels of significance. These results suggest that children prefer to retain their general beliefs but that their sensitivity to the differences in belief structure (MT versus MP) is possibly not yet fully developed.

Experiment 2

The procedures in Experiment 1 were designed to be structurally equivalent to the paper-and-pencil booklet task, but have not previously been tested with college undergraduates. Consequently, we have no frame of reference for development on these problems. To methodologically validate the equivalence of the two paradigms, Experiment 2 examines the counterfactual reasoning tendency of college students with the picture task. If the picture procedure results in a reliable differences between the MT and MP problems for adult reasoners, this would strengthen the claim that this procedure as a new methodology makes direct contact with the former adult methodology, paper-pencil tasks.

We recruited 66 college students to participate in this phase of the study. Half of the participants came from the same population as the children (Dutch speaking, Belgium). The other half came from the same population as the adults from the original adult experiments (English speaking, USA).

Method

Participants

The participants were 30 college students (21 females, 9 males, $M_{\text{age}} = 20.10$ years, age range: 17.9-26.3 years) from a Dutch speaking population and 36 college students (18 females, 18 males, $M_{\text{age}} = 19.6$ years, age range: 18-20 years) from an English speaking population (USA university students). Details about students' ethnic and socioeconomic background were not obtained.

Material, design and procedure

Identical material, design and procedure was applied as those in Experiment 1.

Results

To solve belief-contravening problems, both Dutch and English speaking students selected the generalist path reliable more often than chance (see Table 2). Furthermore, this generalist reasoning tendency was stronger in MT problems than in MP problems (Dutch speaking students, $N_{\text{of non-ties}} = 7$, $z = -2.65$, $p < .01$; English speaking students, $N_{\text{of non-ties}} = 10$, $z = -1.90$, $p < .05$; SR).

Discussion

College age participants show a preference for a generalist reasoning strategy for both MT and MP problems, when there is an explicit visual choice between the generalist and particularist solutions, just as with the paper-and-pencil booklet methodology (e.g., Revlin *et al.*, 2001). The preference for generalities in this pictorial task is greater than in standard paper-and-pencil tasks for both types of problems (see Table 2). The adult students in the present and in prior studies are sensitive to the structure of the problems and show different preferences on MT and MP problems.

Cross-experimental comparison

To assess whether children and adults show the same pattern on these comparable counterfactual reasoning problems, we contrasted Experiments 1 and 2 using Experiment (a proxy for age) as a between subjects variable. Overall, the percentage of participants that prefer the generalist solution is significantly greater in the case of MT problems than MP ones ($N_{\text{of non-ties}} = 24$, $z = -3.27$, $p < .01$, SR). There is no overall difference in belief revision strategy between 7-year-old children and college students (MT, $U = 824$, $z = -.60$, *ns*; MP, $U = 861$, $z = -.19$, *ns*; MWU) nor is there an interaction between the structure of the problem and the age of the participants. Hence, this may indicate that adults and children are behaving similarly. The 18% decrease in the preference of 7-year-olds for the generalist solution between MT and MP (Experiment 1) supports this view (though this difference does not reach conventional levels of significance owing to the substantial variability among the children).

Table 2

Percentages of Generalist Solution-choices in the Experiment 1 and 2 (corrected for memory and comprehension) compared to the results from paper-pencil task of Revlin et al. (2001; Experiment 2B)

Experiment		Modus Tollens		Modus Ponens	
		%	SD	%	SD
1 (children)		88**	.33	70*	.47
2 (adults)	Dutch	93**	.25	69*	.47
	English	92**	.28	75*	.44
Revlin et al. (2001)					
Experiment 1 and 2A		93.9**	.14	39.5	.44

* differ significantly from chance (50%), $\chi^2(1)$, $p < .05$

** differ significantly from chance (50%), $\chi^2(1)$, $p < .001$

General discussion

The present study examined the development of belief-revisioning strategies by comparing two points of the age distribution (7-year-olds and college adults), though clearly not the entire continuous age dimension. We chose the 7-year-olds because previous results showed that between the age of 3 and 5, children's ability to reason counterfactually expands (e.g., Guajardo & Turlay-Ames, 2004) and that by the age of 7 children possess the necessary components to perform the key steps in the Possible Worlds modal logic analysis of belief-revisioning and they start to reason from and spontaneously generate counterfactuals. However, to our knowledge, their counterfactual reasoning abilities in belief revision situations had not been examined before.

Since the paper-and-pencil tasks used in previous studies of adult reasoning were not suitable to test children's reasoning abilities, we opted for a visual, concrete procedure that was developed for adults (Revlin et al., 2005). However after an extensive pilot study (discussed in the Introduction) we concluded that this procedure introduced possible confounds and developed a pictorial task that was similar to the conditions of the paper-and-pencil task. We visually instantiated all the aspects of the belief-contravening problems (statements and possible solutions) and we included questions to control for memory and comprehension difficulties. Our design made it possible to study children's and adults' counterfactual reasoning using the same task, and thereby allowed a comparison of the reasoning pattern of the two groups as well as with previous paper-and-pencil tasks.

This study indicates that 7-year-olds (in Experiment 1), as predicted, were able to reason counterfactually in a belief-revision situation and that they show no reliable difference in their revision strategy in Modus Tollens (MT) and Modus Ponens (MP) problems. Adults (in Experiment 2) exhibit the same pattern of preferences as shown in previous studies in the paper-and-pencil task: a reliable difference in preferences shown for MT and MP problems. However, when we compare age groups in the present study, no significant difference, nor interaction effect between the structure of the belief revision problem (MT or MP) and age is found, owing largely to the variability among the children. This also may be the manifestation of the fully developed ability of counterfactual reasoning that underlies belief revisioning in both 7-year-olds as adults. As mentioned in the beginning, it is only until the age of 5-6 that some researchers have doubts about children's counterfactual reasoning abilities. Future research should investigate belief-revisioning strategies of children under the age of 7.

Alternative accounts

It has not escaped our notice that there are a variety of methodological and theoretical considerations that affect the interpretation of these data. We now turn to a consideration of a few salient issues.

Methodological considerations

It is possible that the way we invite the participants to consider a counterfactual assumption may play a role in such studies. The belief revision problems were based on a pretence structure (“Let’s pretend ...”) and not on a hypothetical structure (e.g., “Assume...”). Amsel *et al.* (2005) pointed out that, although the types of reasoning in both structures are correlated, reasoning in a pretence structure is easier, because it seems to be less constrained by real-world knowledge. Therefore, he concluded that the cognitive process underlying these two forms of reasoning are distinguished but related. It is unlikely, however, that the nature of the conjecture affected the reasoning process in the present study. The adults in Experiment 2, who reasoned with “pretend that ...” showed the same effect of counterfactual structure (MT vs. MP) as did adults in Revlin *et al.* (2001), who were asked to “assume that ...”. The importance of these conjectural terms cannot be assessed adequately with children, who are unlikely to understand the phrase “assume that”.

Besides the structure of the suppositions, another factor could be at play. In the present study some of the participants (both the college students and children) expressed difficulties with revising the association between good and white, or bad and black as in “All of King William’s” (the good king) “knights had white hats”. These cultural ‘stereotype’ beliefs may have come at an earlier age than anticipated and the familiarity with these stereotypes likely influenced the reasoning process (De Neys & Vanderputte, 2011). University students may be able to over-ride these stereotypes more readily than the children, but their existence may be another example of how the statements’ ‘modality’ (law-like character; the commitment to the generalities) is a crucial factor in belief revision. The present study was not designed to address this issue and it should be investigated in future research.

Cognitive considerations

Children, like adults, generate different types of counterfactuals (upward, downward, addition, and subtraction). We note that this ability to generate counterfactuals improves between the age of 3 and 5, with the exception of generating of subtractive counterfactuals (Guajardo & Turley-Ames, 2004). As we mentioned in the Introduction, this is probably related to the fact that subtractive counterfactuals might ask for more cognitive resources (Turley-Ames & Whitfield, as cited in Guajardo & Turley-Ames, 2004). Hence, the

development of a sensitivity for different types of counterfactual situations seems to happen faster than the development of the cognitive ability to generate different counterfactuals. This may have two implications in the present study. First, if we consider MP problems, in which we subtract an item from the general statement, as a type of subtractive counterfactual, processing this type of problem would be more cognitively demanding than MT problems. Secondly, the revision of a strongly believed general statement in general might demand more cognitive resources, which children might not have fully developed, than the revision of a particular statement. Both these implications could explain why the decrease in preference of the generalist solution for MP problems does not reach a sufficient level to be significantly different from the preference in MT problems. It would be worthwhile pursuing this question in future research.

Mental models

The paradigm for studying belief revising in the present study departs in a critical way from those used elsewhere. In the present study, participants have been asked to revise beliefs that are based on prior experience of an integrated knowledge structure. This is consistent with early studies of belief revision with adults, in which the knowledge structure was based on definitional relations available to all participants (e.g., Redding-Stewart & Revlin, 1978; Revlis, 1974; Revlis & Hayes, 1972). Revision of integrated and believable materials produces the pattern of results we have reported here. This paradigm captures the essence of belief-revision in that there is a prior belief or understanding that must be adjusted to make it consistent with a new piece of information or conjecture. In contrast, some studies have used arbitrary relations that are previously unknown to the reasoners, such as "All Pylons had force fields around their cities" (Byrne & Walsh, 2005; Elio & Pelletier, 1997). With these arbitrary relations, adult reasoners either tend to reject the general statements or show no preferred strategy for revising beliefs that differentiate between the general and particular statements. This suggests that to adopt the generalist strategy, the reasoners, whether children or adults, must have an investment in the propositions they are asked to reason about (see also Amsel et al., 2005). This is sensible because to revise beliefs, one must have at least a tacit commitment to an initial set of propositions. To reason counterfactually, there must be some investment in a fact.

The studies with arbitrary relations have produced some results that support a Mental Models account of counterfactual reasoning (e.g., Johnson-Laird, Girotto, & Legrenzi, 2004), which predicts that since Modus Tollens is difficult to reason with and is not a preferred reasoning structure, reasoners should reject the generality in favour of the particular statements in MT problems and accept the generality in MP problems. Clearly, no such pattern has

been observed with either the children or adults in the present study nor in previous studies that used figurines or paper-and-pencil tasks with believed materials. This suggests that when true belief-revision occurs, the process is not simply one of solving a logic problem with arbitrary statements. Belief-revision and its underlying process of counterfactual reasoning are not a process of applying standard logic as logicians have repeatedly reminded us (e.g., Chisholm, 1946; Lewis, 1973; Rescher, 2007).

This is not because children do not reason according to the dictates of Mental Models. Children as young as those in the present study show a pattern of logical inference similar to adults (Markovits, Venet, Janveau-Brennan, Malfait, Pion, & Vadeboncoeur, 1996): they are accurate on Modus Ponens arguments and make errors on Modus Tollens arguments. If their performance in the present study were the result of such logical operations, they would not show the same pattern of reasoning (e.g., a logic/structure effect) as do the adults in the study. The absence of a logic structure effect in children's judgments suggests that they are not following the procedures described by Mental Models theory. It seems reasonable to conclude that if we are to understand true belief revisioning in children and adults, the arbitrary environments will not be a fruitful way to proceed and the Mental Models account must give way to an alternate framework.

Possible worlds and modal logic

The possible worlds logic described in the introduction states that when asked to reason from an assumption that challenges a set of believed propositions, the reasoner selects a possible world that is maximally similar to the pre-assumptive one, but with the propositional relations organised from top to bottom along the lines of "necessity" – that is a modal ordering (Lewis, 1973; Lewis, 1986; Rescher, 1964). To re-establish consistency among the statements that now include the counterfactual assumption, the reasoner seeks to eliminate propositions in such a way as to preserve the most necessary statements. In the present study, that means eliminating the particular statements in favour of the general ones.

This process is clearly seen with MT problems for children and adults. This shows that children not only possess the necessary elemental processing components that adults do, but that they assemble them in the belief-revision process using a generalist strategy as do adults. Children seem to apply this strategy on MP problems, although adults do so to a lesser degree.

For MP problems, the counterfactual assumption diminishes the commitment to the generality. Looking back at the MP problem above (see *Belief revision paradigm*), notice that the counterfactual statement ("this knight has a black hat") directly challenges the law-like generality ("All knights ... have white hats") (Rescher, personal communication; *cf* Ryle, 1949). As such, the

counterfactual assumption seems to reduce the modal status of the generality. Adult belief revisions reflect this effect on the generalities and produce a reduced preference for retaining the general statement in MP problems. It does not produce this result in children who seem not to be sensitive to subtleties in lawfulness. The Possible Worlds Logic gives a plausible account of the pattern of revisions that are exhibited by children and adults.

Conclusion

The present study used belief-contravening problems to examine how children and adults revise their beliefs in the face of a counterfactual assumption. We used a visual methodology that allowed a comparison across age groups. Both adults and 7-year-old children prefer to revise a particular proposition (event) in favour of retaining a general proposition (rule). However, children did not show the same sensitivity (possibly due to cognitive restraints) for the structure of the belief-contravening problem as adults: children's reasoning strategy is not reliably different in Modus Tollens and Modus Ponens problems. This study also showed that adults' preference to retain the generality increases when the belief contravening problem is visualised (in comparison with the paper-and-pencil booklet task). We can conclude that children already at an early age protect their most important beliefs as adults do, but that they are not as sensitive to factors that could influence the modality of their beliefs. These findings of an early appearance of counterfactual reasoning suggest the working of a set of fundamental reasoning processes that are upwardly compatible with adult inference-making and which may require minimal early experiences to be activated.

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Appendix A

Modus Tollens condition – Experiment 1 & 2

Narrative

“Once upon a time there was a very pretty country, Fantasia. The trees and bushes grew beautiful, there was food for everybody and all the people lived in peace. The king of that country was called King William. King William was a good and fair man, who did everything for the people who lived in his country. The people were happy with their king and admired him. Next to that country was the country of another king, King Igor. King Igor was a bad and cruel man. In his country things did not go as well. The trees and bushes grew bad or remained barren, and there was not enough food for everybody, because King Igor took all the money away from the people who lived in his country. King Igor was very jealous of King William. King Igor also wanted a country where everything went that well. That’s why he decided to attack them. He wanted to capture King William and burn the land. Therefore he chose the most evil men in his prison and sent them to Fantasia, the country of King William. The evil men of King Igor looked dangerous. They were riding black horses, wearing black hats and carrying battle-axes to fight. All the knights of King Igor went to the land of the good King William to fight. However, the brave knights of King William fought back. They looked really beautiful and strong. They rode white horses, wore white hats and had swords to fight. The good knights of King William succeed in driving away the evil men in their country and they could keep their land. Together with King William they celebrated their victory.”

Memory-question

Can you tell me what you heard (in the story)?

a. *Who was the good King?*

What was the colour of the hats of the knights of King William?

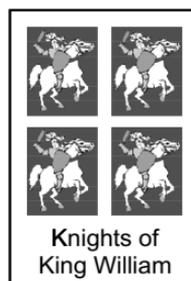
b. *Who was the bad King?*

What was the colour of the hats of the knights of King Igor?

Experimental Task

1a. *So in the story all good knights of King William wore a white hat.*

[Picture of four knights with a white hat + “Knights of King William”]



1b. *This knight wears a black hat.*

[Picture of a knight with a black hat]



1c. *This means that this knight works for the bad King Igor.*

[“Knight of King Igor”]

Knight of King Igor

Let’s pretend now that ... (literally: Let’s now do as if ...)

1d. *... this knight fights with the good king, King William (instead of with the bad king).*

Knight of King William

[“Knight of King William” on top of “Knight of King Igor”]

Check-question 1

*Now the story is not correct anymore... Can you tell me why?
(Because the story said that all knights of King William wear a white hat and this knight wears a black hat, but we pretend now that he also works for King William.)*

(Experimental Task – continuation)

We have two options to solve this problem, to make it correct again:

- a. *Either the knights of King William can also wear a black hat now [Picture of two knights with a white hat and two knights with a black hat + “Knights of King William”]*



- b. *Or we give this knight a white hat.*
 [Picture of a knight with a white hat]



Which option do you chose, do you prefer?

Check-question 2

1. *Why is the story correct again?*

Appendix B

Modus Ponens condition – Experiment 1 & 2

Narrative

“In the Old West there was a city where a lot of people lived. However the people were not that happy there, because they had a big problem. The problem was that their stagecoaches were surprised by terrible thieves. Those stagecoaches were usually filled with money and food for the people in the town. The thieves held up the coaches and took all the money, and also the horses. The thieves all wanted to look dangerous, so they rode on black horses. They carried also a black hat and an axe. In this town also lived a hero and he thought there had to be an end to these thieves taking everything away from the coaches. He wanted to throw all of the thieves in prison, as they should be. The hero called for a group of good, strong men who could help him to imprison the thieves. All the men who went out to help the hero liked to look beautiful and strong, so they rode on white horses, wore a white hat and carried a sword. When the hero had collected enough strong men, they set up a plan. A few of them hid in a coach and the other part hid in the bushes and behind the trees. When the coach passed the road, the thieves attacked them again. But this time the heroes jumped out of the bushes and out of the coach, and surrounded the thieves. The thieves were brought to prison, and from that day on coaches were never surprised, and the people in the town were happy again.”

Memory-question

Can you tell me what you heard (in the story)?

- a. *Who was the good person? (hero)*
What was the colour of the heroes' hats?
- b. *Who was the bad person? (thieve)*
What was the colour of the thieves' hats?

Experimental Task

2a. *So in the story that all heroes wore a white hat.*

[Picture of four people with a white hat + “Heroes”]



2b. *This person is a hero.*

[“Hero”]



2c. *He wears a white hat.*

[Picture of a person with a white hat]



Let’s pretend now that ... (literally: Let’s now do as if ...)

2d. *... this person wears a black hat.*

[Picture of a person with a black hat on top of the picture of the same person but then with a white hat]



Check-question 1

*Now the story is not correct anymore... Can you tell me why?
(Because the story said that that all heroes wear a white hat and this person is a hero ... but we pretend now that he wears a black hat.)*

(Experimental Task – continuation)

We have two options to solve this problem, to make it correct again:

a. *Either, heroes can also wear a black hat now...*

[Picture of two people with a white hat and two people with a black hat + “Heroes”]



b. Or this person is a thief from now on.

[“Thief”]

Which option do you chose, do you prefer?

Thief

Check-question 2

Why is the story correct again?