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Multiple Sources of Competence Underlying the Comprehension of Inconsistencies: A Developmental Investigation

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How do children know the sentence "the glass is empty and not empty" is inconsistent? One possibility is that they are sensitive to the formal structure of the sentences and know that a proposition and its negation cannot be jointly true. Alternatively, they could represent the 2 state of affairs referred to and realize that these are incommensurate, that is, that a glass cannot simultaneously be empty and contain something. In 2 studies, the authors investigated how children (N = 186; ages 4–8) acquire competence to notice inconsistencies. The authors found that children could determine that 2 states of affairs were incommensurate before being able to determine that statements of the form *p and not-p* were inconsistent. The results demonstrate that competence in understanding inconsistent relations depends on (a) the ability to represent 2 states of affairs and (b) the ability to process negation in the context of an inconsistency. The authors discuss these results in relation to sources of competence that may underlie the assessment of such simple inconsistencies.

Keywords: inconsistency, contradiction, negation, language and cognitive development

An inconsistency is any case in which two states cannot simultaneously hold and are therefore mutually exclusive (e.g., if 2 + 2 = 4, then 2 + 2 cannot also equal 5). Inconsistencies arise when an assertion conflicts with current knowledge, when two statements are mutually exclusive, or, more generally, when a set of statements cannot all be true at the same time. The ability to recognize an inconsistency is important in distinguishing true from false information and is critical in scientific, medical, and legal reasoning.

Our aim was to understand the sources of competence underlying the ability to understand inconsistencies. Consider a statement such as "the water is hot and not hot." Adults can clearly understand that such a statement cannot be literally true, and in doing so, they may rely on formal knowledge, semantic knowledge, or both. Specifically, individuals may (a) recognize the formal property of the statement and know that any statement of the form *x and not x* is inconsistent or (b) represent the meaning of "hot water" and "not hot water" and consequently realize the two states of affairs cannot hold at the same time.

Adults' ability to use both semantic and formal knowledge to detect inconsistencies makes it difficult to understand whether both semantic and formal knowledge play a role in the recognition of inconsistencies. Indeed, adults can clearly rely on formal knowledge alone and know that the two statements "Wood contains phlogiston" and "Wood does not contain phlogiston" are contradictory without having any knowledge of the domain at hand. To address this issue, in the present work, we focused on the developmental trajectory by which such abilities are acquired, and to this end examined two types of inconsistencies: those in which knowledge of syntactic structure is sufficient for identifying the inconsistency (e.g., "The glass is full"; "The glass is not full"; syntax-based inconsistencies [SBIs]) and those in which semantic knowledge is necessary (e.g., "The glass is full"; "The glass is empty"; nonsyntax-based inconsistencies [NSBIs]). Given a statement such as "The glass is full," would children find it easier to identify an inconsistency between this statement and the statement "The glass is not full" or "The glass is empty"?

We presented such pairs of inconsistent statements (with matched consistent statements as controls) to children between 4 and 8 years of age. If the ability to recognize NSBIs as inconsistent were to develop before the ability to recognize SBIs, then this would indicate that the initial cognitive processes used to recognize inconsistencies are based on meaning and emerge prior to recognition of any relation between syntactic structure and logical consistency. If the opposite were to hold, then this would suggest that the ability to recognize propositions as inconsistent emerges by noticing formal syntactic relations, which then bootstraps a more general ability. Finally, if competence with both types of inconsistency develops in tandem over time, then this would suggest a general unitary ability underlying both.

Cognitive Mechanisms

Although our domain of inquiry has not been examined by prior work, several lines of research suggest that recognizing simple inconsistencies occurs relatively early in development. Children acquire the ability to note a single statement as inaccurate or false between 1.5 and 3 years of age; for example, they will correct a speaker who refers to *dog* as a cat or makes other mistaken references (Hummer, Wimmer, & Antes, 1993; Pea, 1982). Thus,

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children can relate the state of affairs described by a statement to the state of affairs in the world. Yet, this ability is insufficient for recognizing that a proposition and its negation are necessarily incompatible, which develops later. There is some evidence (Vosniadou, Pearson, & Rogers, 1988) that first graders can detect inconsistencies between a statement and a state of affairs (e.g., "The ball is green" while being shown a red ball) but that only 9-year-old children can detect inconsistencies between two statements (e.g., "The ball is green" and "The ball is not green"). However, other work suggests that in certain cases, children can detect inconsistencies between certain statements, for example, between statements in task instructions, beginning at the age of 6 (Jorgensen & Falmagne, 1992; Markman, 1977; Ruffman, 1999; Russell & Haworth, 1987).

The ability to reason about inconsistencies between statements (hereafter inconsistencies) also develops later: Osherson and Markman (1975) presented children with a series of syntax-based inconsistencies (e.g., "There is a poker chip in my hand and there is no poker chip in my hand") and found that only starting at the age of 7 did children realize that no further evidence was necessary for determining the truth or falsity of the statement. Braine and Rumain (1981) reported that approximately 75% of the 5- and 6-year-old children detected inconsistencies between the predictions two puppets made about the contents of a closed box.

Prior work therefore indicates that detecting inconsistencies between two statements is more difficult than detecting an inconsistency between a statement and the ongoing state of affairs in the world. However, this prior work is agnostic with respect to *how* children come to identify inconsistencies between statements and what mechanism underlies this ability. We therefore constructed our studies to examine three types of explanation for the initial detection of inconsistencies: one arguing that children detect the syntactic structure of the inconsistencies (syntax-based account), the second arguing that children acquire the ability to realize that two states of affairs are incompatible (model-based account), and the third arguing that children acquire pragmatic knowledge about the use of negation.

On the *syntax-based account*, children realize that SBIs of the form *p and not-p* are inconsistent by detecting that the structure of the statement necessarily indicates that the statement is inconsistent. In pioneering work, Osherson and Markman (1975) noted that SBIs of the form *p and not-p* are "true or false by virtue of their linguistic form, rather than deriving their truth-value from any extra-linguistic states of affairs" (p. 214; Braine, 1998; Braine & Rumain, 1981, offers similar arguments). On this approach, SBIs are recognized on the basis of the formal structure of the statement: If it matches a certain schematic form such as p *and* $\sim p$ (sometimes referred to as a *rule* in formal approaches), then it is immediately realized as inconsistent or false. Note that on this approach, the entire form is recognized as a schema, and the negation of one constituent is not processed separately and does not incur additional processing costs. On this account, then, SBIs are detected when linguistic structure can trigger a matching rule.

This account describes the capabilities mediating the comprehension of SBIs but is agnostic about how children develop the ability to understand NSBIs such as "The glass is full" and "The glass is empty," where syntactic form is not diagnostic of an inconsistency. A relatively strong position is that NSBIs are mentally "recoded" in a form similar to that of SBIs (Braine, 1998); that is, the statement above would be recoded into form "The glass is full and the glass is not full," thus triggering the recognition mechanism subserving the comprehension of SBIs. For example, Braine (1998) suggests that "There is nothing in the box" is instantiated as a universal negation because the quantifier *nothing* "is a signal that the argument set is included in the negation" (p. 300). On this view, SBIs should be easier to detect than NSBIs because the latter entail transformation or recoding of an affirmative predicate to negated form (e.g., *empty* → *not full*).

The *model-based account* stems from the premise that although SBIs could indeed be potentially recognized by virtue of their syntactic form, *cognitively*, it is possible to recognize them by other means. For example, given the statements "The box contains a sticker" and "The box does not contain a sticker," one may construct mental representations corresponding to (a) a box with a sticker and (b) a box that is empty (or absent of a sticker), and realize that these two representations cannot hold at the same time. Thus, an inconsistency can be recognized by representing the two states of affairs to which it refers and realizing they cannot jointly hold. On this explanation, the syntactic form of the problem does not play any special role; instead, the representation of semantic content via models is of essence (Johnson-Laird, 1983; Zwaan, 1999). On this approach, a set of propositions is recognized as inconsistent when there is no model in which they all hold (Johnson-Laird, Legrenzi, & Girotto, 2004) and individuals are sensitive to such discorrespondences (Johnson-Laird & Hasson, 2003). On such "model-based" approaches, inconsistencies will be detected when a person can create veridical models of two predications (e.g., full and not full), simultaneously hold these two models in mind, and understand they cannot exist at the same time (see Markovits & Barrouillet, 2002, for an extensive discussion). This account would predict a dissociation between the ability to represent NSBI and SBI contradictions because SBIs, which have the form *p and not-p*, are particularly difficult because one of their clauses contains a negation. Negations are considered difficult because their representation necessitates "tagging" or "annotation" of an affirmative model with an additional bit of information (Bell & Johnson-Laird, 1998; Johnson-Laird, 2001) or a recoding of the negated predicate as an affirmative predicate (e.g., *not-above* → *below*; Fillenbaum, 1966; Hasson, Simmons, & Todorov, 2005; Mayo, Schul, & Burnstein, 2004; Morris, 2003). Such recoding is expected to increase processing complexity and is more difficult for young children given their limited processing capacities (Halford, Cowan, & Andrews, 2007).

Finally, an account based on the pragmatic aspects of the use of negation (*pragmatic-based account* henceforth) would hold that children may consider SBIs of the form *p and not-p* as inconsistent by relying not on syntax or semantics but on their knowledge of situational pragmatics. Specifically, children may treat an ostensible disagreement between two or more speakers as indicative of inconsistency, even if the disagreements are not mutually exclusive. Children may treat situations in which one statement as affirmed and the other denied as diagnostic of an inconsistency, because negation may be most felicitously comprehended within a "context of plausible denial" (Wason, 1965). Knowledge of such a discourse principle suggests that an inconsistency exists in any context in which a negated proposition was presupposed or previously introduced. Thus, the presence of a negation may be a particularly salient cue for disagreement.

This pragmatic-disagreement explanation makes the unique prediction that children could judge any case in which an affirmative and negative statement are presented together as being inconsistent, even when the two statements are consistent. Examining such an account is also important for understanding prior work, as previous investigations (e.g., Braine & Rumain, 1981) used only SBI-based problems (potential hits) but did not include in their design consistent statements with similar syntactic form (potential false alarms). Because of this limitation, what appeared to be correct responses in prior work may have been driven not by logical competence but by response biases (e.g., a yes bias) or pragmatic principles. Thus, to date a pragmatics-based account to what appears to be demonstrated competence with SBIs has not been ruled out.

To summarize, the syntax-based, model-based, and pragmatic approaches make divergent predictions on the sources of difficulty underlying contradictions. On the pragmatic approach, children should either (a) recognize any disagreement between statements as inconsistent or (b) use the presence of a negative as an indication of inconsistency. On the syntax-based approach, processing contradictions of the canonical form *p and not-p* should be easier than or as easy as processing contradictions that do not contain negations because the syntactic form *p and not-p* matches an inferential rule sensitive to syntactic structure (Braine, 1998). In contrast, on the model-based approach, both NSBIs and SBIs demand the construction of models, and the presence of negation in SBIs will serve to increase their difficulty. Therefore, contradictions containing negations should be more difficult. Although it is likely that both types of processes (relatively simple formal logic and model building) are easy for adults, who have more significant working memory resources (Markovits & Barrouillet, 2002), we hoped that by examining their developmental trajectory we could obtain decisive data regarding the underlying sources of competence and their developmental trajectory.

Experiment 1

Experiment 1 consisted of three within-subjects conditions. The participants participated in all three conditions across different sessions. Here we provide the common properties across the conditions, and later we detail those aspects on which the conditions differed.

Participants

One hundred twenty-three participants from five age groups took part in Experiment 1. Table 1 shows the number, age, and gender of participants in each of the five age groups. Participants were recruited from three childcare centers and two schools in the midwestern United States.

Table 1
Participants in Experiment 1

Age group	Number (% male)	Mean age (*SD*)
4-year-olds	24 (58%)	4.5 (0.87)
5-year-olds	24 (50%)	5.6 (0.70)
6-year-olds	26 (42%)	6.5 (0.80)
7-year-olds	25 (48%)	7.4 (0.60)
8-year-olds	23 (57%)	8.7 (0.90)

Materials, Design, and Procedure

The three experimental conditions were presented to children in two sessions over a period of 1 week. One condition was presented in Session 1 and two conditions in Session 2, and the assignment of conditions to sessions was randomized using a Latin square (16 children had a somewhat longer interval, ranging between 8 and 10 days). The procedure in all three conditions was based on the one used by Braine and Rumain (1981) in which puppets make verbal statements about the contents of a box (e.g., Puppet 1: "There is a sticker in the box"; Puppet 2: "There is no sticker in the box"). After being presented with these statements, the participants were asked to recall the puppets' statements and were prompted to do so until the statements were correctly repeated. Only at that point were they probed for their comprehension of the statements. Presentation of the puppets' statements was randomized to control for order effects and to ensure that affirmed or negated statements were equally often presented as the first statement of the pair (analyses revealed no effect of presentation order, and this factor is not discussed further). A summary of the characteristics of the three conditions is presented in Table 2.

In all three conditions, two factors were manipulated: (a) whether the two statements were consistent or inconsistent and (b) whether the pair of statements consisted of two affirmative statements, or one affirmative and one negative statement. The crossing of these two factors resulted in four kinds of statement pairs: SBIs and NSBIs and their respective *consistent* baseline control statements (see Table 3). The control conditions for SBIs (SBI-control) allowed accounting for possible response biases that may be prompted by the presence of a negation and an affirmation. The control condition for NSBIs (NSBI-control) accounted for any other biases such as conservative response biases (saying no more than would be expected by chance). For each of these pairs of statements, participants were asked, "Could the puppets both be right?" Participants did not see the contents of the box because the results of pilot studies indicated that seeing the contents led children to assess the perceived accuracy of speakers rather than to focus on the presence or absence of inconsistencies.

Analysis Method

As mentioned in the introduction, prior investigations (e.g., Braine & Rumain, 1981) did not include control conditions that consisted of consistent contents. Such statements were included in the present study, and for this reason, accuracy was operationalized as the difference between correct responses to inconsistent statements (hits) and incorrect responses to the consistent statements (false alarms). This comparison derives its logic from signal detection, which is bias free (Wickens, 2001) and is a more reliable assessment of competence than is afforded by hit rates alone.

Furthermore, individual response consistency was also examined because aggregated response patterns may obscure underlying data trends (Siegler, 1987). For example, if two children recognize an inconsistency as such, one may do so due to awareness of the sentence's meaning, but another may suppose that any circumstance in which one affirmative and one negated statement are

Table 2
Summary of Stimuli for Experiment 1

Condition	Mode of content presentation (SBI example)	Comprehension question
1	Puppet 1: There is a sticker in the box. Puppet 2: There is no sticker in the box.	Could both puppets be right?
2	Puppet 1: There is a sticker in the box and there is no sticker in the box.	Is the puppet right?
3	Puppet 1: Right now there is a sticker in the box. Puppet 2: Right now there is no sticker in the box.	Can they both be right at the same time?

Note. SBI = syntax-based inconsistency.

given together indicates disagreement, and thus is inconsistent (e.g., "There is a sticker in the box and there isn't a ball in the box"). The latter response likely originates in pragmatics, because in conversation, negation is often used to deny an alternative (Wason, 1965). Collectively, our control statements provided information on the cognitive bases underlying behavior that was unavailable in previous studies (e.g., Braine & Rumain, 1981).

Experiment 1/Condition 1: Information Presented by Two Speakers

Method

Children were tested individually. They were told that sometimes both puppets could be right, sometimes only one puppet could be right, and sometimes neither puppet could be right. Children were given 16 total trials, four of each type (see Table 3), in which both puppets made a prediction about the contents of the box. In each trial, participants were instructed to close their eyes while the experimenter "set up" the trial by changing the contents of the box. They were told the statements by each puppet and then asked, "Could both puppets be right?"

Results

From the responses, we derived two accuracy measures that reflected the child's knowledge of SBIs and NSBIs, and we evaluated these performance indicators across the five age groups. Accuracy for SBIs was a composite measure of correctly identifying SBIs as inconsistent (i.e., a "hit") minus wrongly identifying SBI-control statements as inconsistent (i.e., a "false alarm"). Accuracy for NSBIs was derived from correctly identifying NSBIs as inconsistent (i.e., a "hit") minus wrongly identifying NSBI-control statements as inconsistent (i.e., a "false alarm"). These composite accuracy measures (hits–false alarms) are presented in Figure 1, and Table 4 in addition reports the proportions of hits and false alarms.

Overall accuracy increased from age 6 on and was significantly greater for NSBIs than for SBIs. In addition, the advantage for NSBIs appeared by age 6, but was absent before (see Figure 1). These patterns were confirmed by a 2 (inconsistency: SBI, NSBI) × 5 (age) analysis of variance (ANOVA) that revealed a reliable effect of age, $F(4, 117) = 11.4$, $p < .01$; type of inconsistency, $F(1, 117) = 7.4$, $p < .01$; and an interaction, $F(4, 117) = 18.0$, $p < .01$. A second ANOVA that excluded the two youngest age groups (4- and 5-year-olds) demonstrated no interaction, $F(2, 74) = 2$, $p > .20$, suggesting that the youngest children (unlike older ones) exhibited very low accuracy levels for both types of inconsistencies. The results demonstrate that 5- and 6-year-olds not only produced some correct responses for NSBIs (and to a lesser extent SBIs) but also produced high levels of false alarms. Only 7- and 8-year-olds produced high hit rates to inconsistencies and low levels of false alarms to consistent trials.

A closer examination of the individual response patterns can help identify reasons for poor accuracy in recognizing inconsistencies. To this end, we fit the individual response patterns to a priori defined patterns (see Table 5). A participant was coded as using a certain pattern if his or her responses matched a proposed pattern for at least 75% of the responses. Children who did not match any of the proposed patterns were coded as "No pattern." Interrater reliability was 95% before discussion (Cohen's $\kappa = .82$).

A chi-square analysis indicated significant age-related changes in response patterns (see Figure 2), $\chi^2(12, N = 122) = 20.33$, $p <$

Table 3
Four Statement Types Used in Experiment 1

Baseline control	Affirmation-Negation	Affirmation-Affirmation
Inconsistent	SBI (no)[a] P1- There is a sticker in the box. P2- There is no sticker in the box.	NSBI (no) P1- There is a sticker in the box. P2- The box is empty.
Consistent	SBI-control (yes) P1- There is a sticker in the box. P2- There is no ball in the box.	NSBI-control (yes) P1- There is a sticker in the box. P2- There is a ball in the box.

Note. SBI = syntax-based inconsistency; NSBI = nonsyntax-based inconsistency; P1 = Puppet 1; P2 = Puppet 2.
[a] Correct responses to the question "Could both puppets be right?" is provided in parentheses.

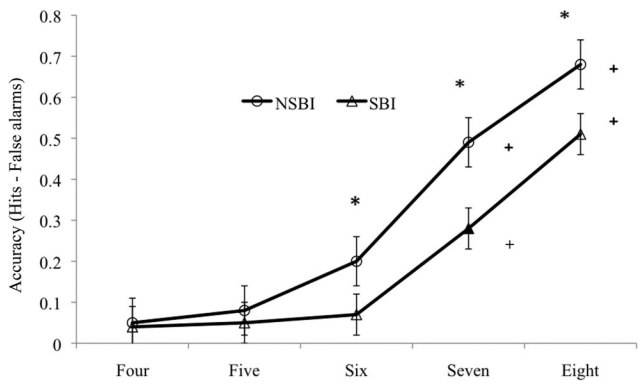

Figure 1. Results of accuracy analysis for syntax-based inconsistencies (SBI) and nonsyntax-based inconsistencies (NSBI) with standard error bars (Experiment 1). An asterisk signifies a significant difference between pairs; a plus sign indicates a significant difference from zero.

.01. The majority of 4- and 5-year-olds were coded as using a "Yes Bias." Although most 6-year-olds showed no consistent pattern, approximately 10% consistently detected only NSBIs. Approximately 50% of 7-year-olds detected NSBIs, whereas only 15% detected both types of inconsistencies. Over 50% of 8-year-olds detected both types of inconsistencies, and an additional 20% detected NSBIs only. One child detected 75% of SBIs (matching our minimum level for consistency) yet detected only 50% of NSBIs.

Discussion

These data clearly demonstrate a difference in competence with SBIs and NSBIs that is maintained across a number of age groups. First, there was a clear trend in increased accuracy with age. In general, 4-year-olds demonstrated a yes bias, 5- and 6-year-olds increased both the number of hits (e.g., correctly identifying true inconsistencies) and false alarms (e.g., incorrectly classifying consistent statements as inconsistent). That is, although these age groups increased their tendency to respond no, they failed to distinguish when this response was warranted. Seven- and 8-year-olds produced significantly more hits than false alarms. Although few young children showed mastery of inconsistencies, competence with NSBIs was found earlier than competence with SBIs (seen in the response patterns of 6- and 7-year-olds). More important, on the interindividual level, children who demonstrated mastery of SBIs almost always showed mastery of NSBIs (95%, only one child was an exception), but the reverse did not hold. Thus, the two abilities were not independent.

Although these data suggest that children are more adept with NSBIs and that this ability solidifies around age 7, there are some limitations to the design used in this experimental condition. First, the use of two sources of information (two puppets) could confuse or obscure the relatedness of the statements. Second, even though the children recalled both statements before answering the question, presenting the statements separately may still increase memory demands because at that point, the two statements need to be integrated, and younger children might be particularly susceptible to forgetting the content of the first statement (or perhaps truncating the second assertion; Morris & Sloutsky, 2002). We therefore constructed Condition 2, in which we presented the two statements as spoken by one speaker in a single-sentence frame (as in Osherson & Markman, 1975).

Experiment 1/Condition 2: Information Presented by a Single Speaker

This condition was very similar to Experiment 1 except that the two statements were conjoined with the word *and* and presented by one puppet instead of two. The presence of negations or affirmations resulted in the same four statement types used in Experiment 1. The procedure, materials, coding, and analysis were similar to Experiment 1 (changes are detailed below).

Method

The materials and procedure were as in Condition 1, with the following modifications: One box and one puppet were used instead of two, and only one puppet made predictions about the contents of the sealed box. Each child saw 16 statements, four of each type. The puppet, called Fuzzy, made predictions about the contents of the box, and the participants were asked, "Is Fuzzy right?"

Results and Discussion

Composite accuracy measures (hits–false alarms) were derived as in Condition 1. The result patterns were very similar: an overall

Table 4
Accuracy Scores for Experiment 1, Condition 1

Age	SBIs (hits)	SBI-control (false alarms)	SBI accuracy (hits–false alarms)	NSBIs (hits)	NSBI-control (false alarms)	NSBI accuracy (hits–false alarms)
4	0.09	0.06	0.03	0.10	0.05	0.05
5	0.24	0.21	0.03	0.42	0.36	0.06
6	0.44	0.38	0.06	0.59	0.39	0.19*
7	0.53	0.26	0.27†	0.70	0.22	0.48†*
8	0.67	0.16	0.51†	0.86	0.12	0.74†*

Note. SBI accuracy values were derived from the SBI score (correctly answering no)—SBI-control score (wrongly answering no). NSBI accuracy scores were similarly derived. SBI = syntax-based inconsistencies; NSBIs = nonsyntax-based inconsistencies.
† Indicates a significant departure from zero. * Indicates a significant difference between SBI Accuracy and NSBI Accuracy scores for an age group.

Table 5
Proposed Individual Response Patterns and Coding Criteria

Pattern	Criteria
SBI + NSBI	Accurate performance on NSBIs and SBIs
SBI only	Accurate performance on SBIs but not on NSBIs
NSBI only	Accurate performance on NSBIs but not on SBIs
Pragmatic-negation	Responding no to any statement that contained a negation
Pragmatic-disagreement	Wrongly determining that an inconsistency exists in *all* conditions[a]
Acquiescence (yes) Bias	Producing a yes response to all conditions[b]
None	Does not correspond to any of the other predefined patterns

Note. SBI = syntax-based inconsistency; NSBIs = nonsyntax-based inconsistency.
[a] May arise if a child decides that two speakers are inconsistent when they do not agree with each other. [b] Probably based on a lack of understanding (e.g., Fritzley & Lee, 2003).

improvement in accuracy with age, with an advantage for NSBIs starting at the age of 6. These patterns were statistically confirmed by a 2 (inconsistency: SBI, NSBI) × 5 (age) ANOVA showing a main effect of inconsistency, $F(1, 117) = 12.7$, $p < .01$, and age, $F(4, 117) = 10.2$, $p < .01$. As in Condition 1, the significant interaction, $F(4, 117) = 10$, $p < .01$, disappeared when 4- and 5-year-olds were removed from the analysis, $F(2, 74) = 1.6$, $p > .10$. Planned contrasts revealed that greater accuracy for NSBIs was found from age 6 onward (all *p*s < .03).

The individual response patterns were also nearly identical to those from Condition 1, showing significant differences in response patterns across age groups, $\chi^2(12, N = 122) = 60.2$, $p < .01$. As in Condition 1, a small proportion (approximately 15%) of 6- and half of 7-year-olds produced accurate responses to NSBIs alone (but not SBIs), whereas nearly 40% of 8-year-olds accurately detected both types of inconsistency. On the group level, the overall response patterns in Conditions 1 and 2 were remarkably similar, pointing to earlier mastery of NSBIs and more accurate performance for these inconsistencies within age groups. As in Condition 1, nearly all who correctly solved SBIs also correctly solved NSBIs (95%).

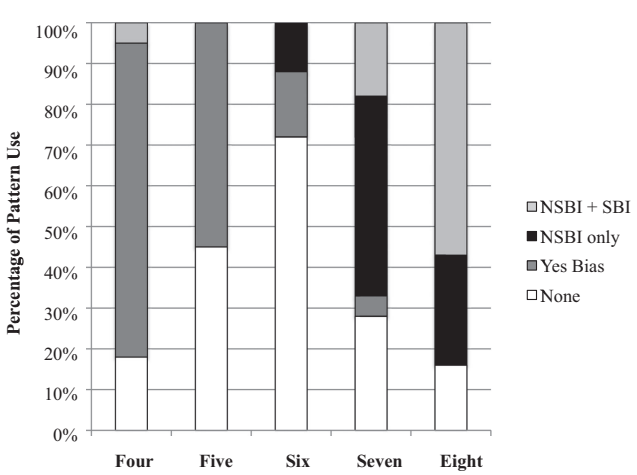

Figure 2. Percentage of children using each response pattern in each age group (Experiment 1). Response patterns in Conditions 2 and 3 were almost identical to those in Condition 1 and are therefore not depicted. Syntax-based inconsistency (SBI) only was omitted because only one child fit that classification. NSBI = nonsyntax-based inconsistency.

Experiment 1/Condition 3: Emphasizing the Temporal Dimension

It is possible that relatively poor performance seen for the younger age groups in Conditions 1 and 2 occurred because they had treated the two assertions as referring to events that occur at different times (e.g., [before] "There was a pencil in the box"; [now] "There is nothing in the box"). If so, then children may judge inconsistencies as consistent. Indeed, children may sometimes treat the two parts of inconsistencies as if they pertain to different referents (e.g., Sharpe, Côt, & Eakin, 1999); when presented with statements such as "My dinner was good and bad," children have been shown to treat each predicate as referring to a separate part of the meal (e.g., "The fish was good but the potatoes were bad"), thus eliminating the inconsistency. This possibility was examined in Condition 3. To this end, we modified the instructions to explicitly describe the two statements as referring to states of affairs occurring at the same time.

Method

The design, materials, and procedure were identical to Condition 1 with a minor change to the instructional protocol that made explicit that the description of the box contents referred to its contents at the same time. An example trial could say: "Puppet 1 says, 'Right now there is a sticker in the box.' Puppet 2 says, 'Right now there is no sticker in the box.' Can they both be right at the same time?"

Results and Discussion

We derived the accuracy measures as in Conditions 1 and 2 and entered them into an ANOVA. Accuracy improved with age, $F(4, 117) = 14.3$, $p < .01$, and was greater for NSBIs, $F(1, 117) = 9.8$, $p < .01$. Planned contrasts indicted an advantage for NSBIs from age 6 on (all *p*s < .05). As in Conditions 1 and 2, there was a reliable interaction between the two factors that did not appear after removing the two youngest age groups, $F(2, 74) = 1.8$, $p > .10$. An analysis of individual response patterns indicated significant age-related differences in individual response patterns, $\chi^2(12, N = 122) = 1.2$, $p < .01$, that were nearly identical to those reported in Condition 1. The results of Condition 3 showed that emphasizing the temporal overlap between events did not impact young children's accuracy—in fact, the results were very similar to

those in Conditions 1 and 2: (a) On the group level, children mastered NSBIs before SBIs, and (b) on the individual level, competence with NSBIs was sometimes found in absence of competence with SBIs. Specifically, approximately 15% of 5-, 45% of 6-, and 20% of 7-year-olds demonstrated mastery of NSBIs only. However, the opposite did not hold in that all of the children in this condition who demonstrated mastery of SBIs demonstrated mastery of NSBIs (20% of 7- and 55% of 8-year-olds). This suggests that errors in Experiment 1 were not due to erroneous temporal representations. Finally, a comparison of accuracy across all three conditions via a 5 (age) × 3 (condition) × 2 (inconsistency) ANOVA indicated no significant differences in inconsistency detection between the conditions, $F(8, 117) = 0.76$, $p > .20$.

The fact that children acquire competence with NSBIs prior to acquiring competence with SBIs raises the possibility that there exists an intermediate point in development where before SBIs are mastered, they are first interpreted as NSBIs; that is, the negated predicate is represented or recoded as an affirmation, and the child then examines whether the two states of affairs are commensurate. Note that using this strategy in the present experiment would result in incorrect answers to SBIs: To illustrate, a child recoding "There is a sticker in the box and there is no sticker in the box" to an affirmative of the form "There is a sticker in the box and there is something else in the box" would wrongly determine the statement as consistent. If such a transition point exists in which NSBIs bootstrap knowledge of SBIs, then we would predict that we should find a group of children who have mastered NSBIs and the consistent control statements, but systematically err on SBIs.

To examine this possibility, we first identified which children performed highly accurately (>87% correct) on all trials that *were not* SBIs, independent of their performance on SBIs (*n*s = 29, 30, and 31 in Conditions 1–3, respectively). Within this high-accuracy group, we identified those children who performed poorly on SBIs (0 or 1 answers correct in the four trials) and determined their age relative to the other children in this high-accuracy group (*n*s = 9, 11, and 9 in Conditions 1–3, mean ages = 4 years 11 months, 4 years 9 months, and 4 years 9 months, respectively). As expected, these children, who performed accurately on all problems except for SBIs, were reliably younger than those who performed accurately on all problems: Condition 1, Mann-Whitney U = 38.5, $p < .01$; Condition 2, Mann-Whitney U = 52.0, $p < .05$; Condition 3, Mann-Whitney U = 39.0, $p < .01$. This analysis provides support for a transitional point in development characterized by a nascent understanding of the concept of inconsistency and consistency but that is accompanied by systematic errors in comprehension of SBIs, strongly suggesting that such SBIs are recoded into a non-negated form.

Experiment 1: Discussion

Our results demonstrate that children understand NSBIs before they understand SBIs. In general, 4- and 5-year-olds did not display competence with either type of inconsistency, 6-year-olds only demonstrated competence for NSBIs, and 7- and 8-year-olds showed reliable accuracy for both NSBIs and SBIs. However, even for the oldest age group, SBIs were associated with lower accuracy than NSBIs. The increase in accuracy with age was driven by a decrease in false alarms for consistent statements and an increase in correct recognition of inconsistencies. Finally, there was no evidence for a pragmatic approach in which children treated disagreements as inconsistencies.

Altogether, these data clearly indicate that competence with NSBIs emerges earlier than competence with SBIs. Perhaps more important are the findings from the individual response patterns, which demonstrated that on the individual level, these two competencies are not independent. Specifically, on the individual level, mastery of SBIs (~7 years of age) was always accompanied by mastery of NSBIs (with the exception of one participant), but competence with NSBIs was very often not accompanied by competence with SBIs. Thus, NSBIs were understood before SBIs, and competence with SBIs virtually necessitated competency with NSBIs, but the converse did not hold.

Experiment 2

Experiment 1 indicated that children's ability to recognize inconsistencies increased dramatically from age 6 onward and revealed strong dissociations between SBIs and NSBIs. In Experiment 2, we examined whether the poor performance displayed by younger children could have resulted from them interpreting the statements as noncommitting *predictions* rather than concrete *observations*, that is, interpreting them as "it is possible that . . . " If the statements were interpreted as predictions, then it is possible that such predictions might not be treated as inconsistent due to an elliptical interpretation in which each prediction is considered to be a separate possibility. This account cannot easily explain the developmental trend seen in Experiment 1, because it would be committed to stating that the increased accuracy with age indicates a *decreasing* tendency to interpret statements as predictions. Still, such a bias could introduce noise into the data, and we therefore addressed it in the present study by making it clear that the puppets' utterances were made after they had *observed* a concrete state of affairs.

We included two other modifications in the study. First, we included a condition in which children responded by indicating whether they thought the observations were "ok" or "silly." This removed the need to make meta-linguistic judgments of the sorts prompted in Experiment 1, which might be particularly difficult for younger children (foreshadowing the results, this manipulation did not increase accuracy). Second, we asked children to explain their reasoning after each response, a method used by Cummins (1978). This was done to assess whether children have an explicit understanding of the principle that all SBIs are necessarily inconsistent.

Method

Participants. Sixty-three children participated in the study. Participants were 21 five-year-olds ($M = 5.6$, $SD = 0.9$; 13 girls, 8 boys), 20 six-year-olds ($M = 6.4$, $SD = 0.6$; 13 girls, 7 boys), and 22 seven-year-old children ($M = 7.4$, $SD = 0.55$; 12 girls, 10 boys) from three schools in the midwestern United States. These ages were chosen because of the significant changes in performance measured in Experiment 1.

Design and materials. The statements and materials used in Experiment 1 were used for this experiment.

Procedure. As in Experiment 1/Condition 3 puppets made verbal statements about the contents of a small box (e.g., Puppet 1:

"There is a sticker in the box right now"; Puppet 2: "There is no sticker in the box right now"). To emphasize that the statements were made after the puppets observed the contents of the box, the puppets would enter a larger box through two small doors covered by curtains, and once inside, the puppets would look into the smaller box (located inside the larger box). They would then reappear from the larger box and report what they had seen in the smaller box. Thus, children could not see the contents of the smaller box.

Two dependent measures were collected for each child, in two sessions separated by approximately 1 week (M = 8 days). In Condition 1 (the *observation condition*), children were probed for their knowledge of whether the two statements are consistent. This condition was structured to be similar to prior studies in the literature that evaluated children's competence with contradictions (Braine & Rumain, 1981; Cummins, 1978; Morris & Sloutsky, 2002; Osherson & Markman, 1975). The crucial part of the instructions in this condition was:

> These puppets will tell us what they saw. . . . They go into the doors in the large box to look at what is inside the small box . . . What I'd like you to do is figure out if they are both right at the same time. What that means is that puppet A is saying a right thing and Puppet B is also saying a right thing about what is now inside the box.

In Condition 2 (the ok-silly condition), children evaluated the pairs of statements as ok or silly. In both the observation and ok-silly conditions, the children were asked to explain their response after each trial. Half the participants participated in the observation condition in Week 1 and the ok-silly condition in Week 2, whereas the other half participated in the opposite order. As in Experiment 1, presentation orders were randomized to control for order effects and to ensure that negated and affirmed items were equally presented as the first item of the pair.

Results

Accuracy in observation condition. Accuracy was derived as in Experiment 1. The composite accuracy measures (hits–-false alarms) are presented in Figure 3. Analyses revealed main effects of age, $F(2, 62) = 8.4$, $p < .01$, as older children were more accurate, as well as a main effect of inconsistency, $F(1, 62) = 11$, $p < .01$, demonstrating greater competence with NSBIs than with SBIs. Planned contrasts indicated this advantage held for 6- and 7-year-olds ($p < .05$). There was also a reliable interaction between age and type of inconsistency, $F(2, 62) = 6.7$, $p < .01$, demonstrating the advantage for NSBIs was relatively weaker for 5-year-olds.

Individual differences in the observation condition. We coded and analyzed individual-difference patterns as in Experiment 1. There were significant age-related changes in response patterns, as evidenced by a chi-square of the frequencies of response patterns across age groups, $\chi^2(6, N = 63) = 123$, $p < .01$. Specifically, 5-year-olds mostly showed an acquiescence (yes response) bias or no consistent response pattern, 6-year-olds mostly showed no consistent pattern with 25% of the age group showing sensitivity to NSBIs, and 7-year-olds tended to show competence with NSBIs alone (50% of participants) or competence with both types of inconsistency (15% of participants).

Accuracy in the ok-silly condition. Composite accuracy measures (hits–false alarms) were derived for this condition as in the observation condition. The results were very similar to the observation condition: There was a main effect of age, $F(2, 62) = 7.8$, $p < .01$, showing that older children were more accurate, an effect of inconsistency type, $F(2, 62) = 5$, $p < .01$, as NSBIs were better understood by 6- and 7-year-olds ($p < .05$). There was also a reliable Age × Type of Inconsistency interaction, $F(2, 62) = 5.6$, $p < .01$, demonstrating that the advantage for NSBIs was relatively weaker for 5-year-olds. Thus, the ok/silly formulation resulted in very similar results to those of the observation condition and Experiment 1.

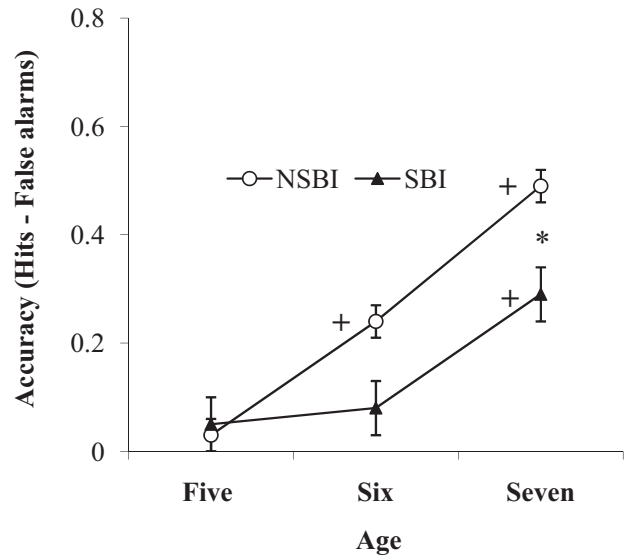

Figure 3. Response accuracy in the observation condition (+*SE*) in Experiment 2. An asterisk signifies a reliable difference between pairs; a plus sign indicates a significant difference from zero. NSBI = nonsyntax-based inconsistency; SBI = syntax-based inconsistency.

Children's explicit awareness of inconsistencies. Was children's performance driven by acquisition of explicit knowledge pertaining to formal rules or semantic knowledge? To examine this issue, we coded participants' verbal explanations of their responses. These were coded using categories similar to Cummins (1978), and the main interest was in whether children used explanations that would indicate knowledge of the principle of inconsistency (e.g., "It can't be both a sticker and not a sticker"). There were five coding categories: no explanation, guess ("I think there is a dog in the box"), empirical ("I can't see in the box"), reiteration ("You said a sticker AND no sticker"), and inconsistency knowledge ("There can't be a sticker if the box is empty"). These response categories accounted for 98% of responses and were coded reliably by two hypothesis-blind coders (95% agreement before discussion; $\kappa = .78$).

Our analysis of these types of explanations across the age groups revealed significant age-related differences across the age groups in both the observation condition, $\chi^2(8, N = 63) = 51.14$, $p < .01$, and the ok-silly condition, $\chi^2(6, N = 63) = 52.2$, $p < .01$. Of importance, however, when presented with inconsistent statements, children rarely used explanations that indicated inconsistency knowledge. In the observation condition, no such explanations were given by any of the children, and in the ok-silly

condition, these accounted for 6% of the explanations in the 6-year-old group and 19% of the explanations in the 7-year-old group. Instead, improvement across ages was seen in reduced proportion of "no response" and "empirical" explanations with age. Although these results do indicate improvement in explanation ability associated with age, they also show that explicit awareness of the principles of inconsistency lags behind children's ability to notice inconsistency.

Experiment 2: Discussion

Experiment 2 corroborated the findings of Experiment 1 and provided no support for the hypothesis that the observed response pattern in that study derived from understanding the statements as putative observations: Competence for NSBIs was stronger than that for SBIs and appeared to develop earlier. By examining children's explanations for their decisions, we identified age-related improvements in explanation ability but found no evidence indicating that children acquire an explicit understanding that certain syntactic forms are by definition inconsistent. Thus, explicit understanding of SBIs lags significantly behind performance.

General Discussion

Our study aimed to examine the sources of initial competence underlying the ability to recognize an inconsistency and to evaluate whether such sources of competence develop in independent trajectories. Our findings suggest that children begin detecting inconsistencies when they can represent and compare the two situations referred to in the inconsistency. Importantly, they do so before they can detect inconsistencies whose syntactic structure is unambiguously diagnostic of a contradiction. These findings from Experiments 1 and 2, taken together with children's explanations for their behavior (Experiment 2), do not lend support to the notion that the syntactic structure of inconsistencies plays an essential role in their initial recognition. Specifically, our results demonstrate that understanding NSBIs is simpler and quite different from understanding SBIs. From the perspective of current theories of the representation of inconsistency, such results are more compatible with the view that detecting an inconsistency depends on creating models of the situation referred to in the statement rather than the use of inferential rules that are triggered by the syntax of the statement. Finally, we found no evidence that children used situational pragmatics to detect inconsistencies.

Some researchers have argued that the source of the difficulty in processing inconsistencies is in acquiring a formal rule that marks SBIs as false (e.g., Braine & Rumain, 1981). Such "formal" accounts can accommodate the present results by positing that the comprehension of NSBIs and SBIs relies on separate sources of competence, corresponding roughly to (a) the ability to represent two states of affairs and (b) the acquisition of a formal rule. However, this account would need to explain why children's competence with NSBIs appears prior to competence with SBIs (on the aggregate group level) and why understanding NSBIs appears to be a necessary *precursor* to competence with SBIs (on the individual level). The latter point is particularly difficult for formal accounts: These accounts could easily accommodate a reversed pattern of results for which SBIs are acquired earlier, as they could argue that competence with NSBIs is achieved when children acquire formal mechanisms that enable comprehension of contradictions such as *full and empty* by matching it to *full and not-full*, thus triggering a formal rulelike schema (as in Braine, 1998). However, this account cannot explain why NSBIs are mastered earlier if they were to rely on the same type of rules that more directly match syntactic structure.

Theoretical accounts grounded in model-based approaches appear to better account for the present findings than rule-based or pragmatic accounts. Such approaches (e.g., Johnson-Laird, 1983; Zwaan, 1999) would suggest that inconsistencies of different sorts are understood via a single general principle—model construction—but the source of increased difficulty for SBIs arises from the need to veridically represent the negated predicate in conjunction with the affirmative predicate. Developmentally, children's understanding of negation is initially limited to certain senses (e.g., nonexistence), but they do acquire adultlike negation use by late preschool (Bloom, 1970; Kim, 1985) and can display sophisticated competence with negation in certain contexts (see Crain, Gualimini, & Meroni, 2000). The difficulty of SBIs cannot therefore be reduced to difficulty in representing a negated predicate per se. Instead, it points to the difficulty of conjointly representing both the negated and affirmative predicate and being able to assess them in relation to each other. Thus, it is quite possible that a child would be able to understand a sentence such as "The glass is not full" but still not be able to understand the inconsistency between this proposition and "The glass is full." We suggest that the difficulty of SBIs may be due to the difficulty that negation introduces into the assessment of these statements in relation to each other, namely, holding these statements in working memory, creating veridical representations, and verifying these statements on the basis of knowledge in long-term memory.

It could be that the representation of negation imposes a working memory load because it makes it more difficult to maintain the affirmative and negated predicates in working memory while simultaneously evaluating their consistency. In prior work (Morris & Sloutsky, 2002), we have found that when reasoning about SBI contradictions, preschool children appear to "truncate" one of the predicates of the contradiction, and furthermore, they truncate contradictions much more often than conjunctions that are not contradictions. Of interest is that although children truncated these statements, they correctly recalled the entire statement before and after reasoning. A complete truncation of a predicate would lead to an inability to recognize an inconsistency, leading to a nonsystematic, or yes-response pattern. Alternatively, increased working memory load might lead to truncating the negation operator, resulting in a mental representation of two affirmative prepositions and a yes-response pattern.

The account we outline above is based on errors that occur during retrieval of content from working memory or during the reasoning process itself, because as we noted, children successfully repeated the statements before answering the experimental questions. This pattern corroborates prior work on memory and cognition (e.g., fuzzy trace theory; Brainerd & Reyna, 1993) demonstrating a "memory-reasoning dissociation" that refers to the fact that children can remember and understand individual propositions, but they may lack the conceptual ability to relate them to each other. Our findings also support this dissociation in showing that although children can encode the syntactic form of SBIs, they do not rely on it as a diagnostic cue for recognizing

inconsistency; thus, the surface structure of the statement does not seem to be used functionally during the acquisition of inconsistencies.

The representation of negation is a more complicated operation than the representation of affirmation, as it involves, at minimum, representing another unit of content. In practice, the mental operations that take place during the representation of negation are quite complex. Comprehension of negation seems to proceed by first representing what is said to be not the case (i.e., constructing a model of affirmation), followed by an incorporation of negation into that representation within 1 s or so (Hasson & Glucksberg, 2006; Kaup, Lüdtke, & Zwaan, 2006). When this process fails, such as when people are under cognitive load, they sometimes misrepresent a negated proposition as if it were affirmative (Gilbert, 1991). In summary, the additional information and processing steps associated with negation increase problem *complexity*, defined as the number of relations that can be processed simultaneously (Halford, Wilson, & Phillips, 1998). Problem complexity has been implicated in age-related increases in performance on a variety of tasks, including class inclusion and transitivity (Halford, 1993).

Prior work examining inconsistencies focused on SBIs (Braine & Rumain, 1981; Osherson & Markman, 1975) and attributed their difficulty to a failure to reason analytically about the form of the statement (i.e., apply a schema or formal operation applicable to the statement form) or to an inability to understand that contradictions can be assessed without empirical support. Because our results point to a semantic basis for competence with inconsistency, they raise the question of why inconsistencies were detected at 6, but not at 4 or 5 years of age? Although this question calls for an interpretation of a null effect, it warrants discussion in light of what is known from prior work. This question is particularly interesting because by the age of 4, children know that statements can be wrong with respect to the world (external inconsistency; Hummer et al., 1993), can think counterfactually (see Harris, 2001, for review), and realize that agents can have false beliefs (Wellman, Cross, & Watson, 2001). This suggests that children lack either knowledge of the concept of a contradiction or the ability to evaluate them. As suggested by Osherson and Markman (1975), children may lack the understanding that certain statements can be assessed independent of empirical support, and Braine and O'Brien (1991) similarly suggested that the ability to implement such "decontextualized" assessment could increase with age.

Another possibility is that children do not have a sufficient understanding of the semantics of conjunction (which was explicitly introduced in Experiment 1 [Condition 2] and was implicit in the other procedures). Although children have some understanding of the connective *and*, as demonstrated by correct use in natural discourse (Bloom, Lahey, Hood, Lifter, & Fiess, 1980; Fenson et al., 1994; Morris, 2008), they demonstrate limited understanding of the conditions under which conjunctions are true or false until middle childhood (Morris & Sloutsky, 2002; Osherson & Markman, 1975). Yet, even mastery of conjunction in its everyday use might be insufficient. It is likely that in everyday discourse, the conjunctions most often encountered are either potentially valid ones (where both constituents can be true at the same time) or ones that are invalid because one of the constituents does not hold. In contrast, contradictions may be more rarely experienced, resulting in slower mastery of this particular type of statement. Furthermore, if experience indicates that a false conjunction is one that is typically associated with one of the constituents being false, then it could be difficult to apply the notion of the falsity to a new form of conjunction where the truth of neither constituent can be ascertained. Beyond the lack of knowledge of contradictions or semantics of conjunction, younger children's poorer ability may reflect one of several types of insufficient information-processing constraints such as lesser working memory capacity or an inability to maintain increasing complex relations between items. Researchers have shown that working memory resources are positively related to reasoning effectively under conditions of uncertainty (e.g., Markovits & Doyon, 2004). In addition, around 4 or 5 years of age, children seem to develop the ability to process increasingly complex relations between tokens (Halford et al., 1998). Assessing the materials in the present study demanded evaluating a conjunction relation with an arity of two (two arguments) against an external criterion that indicates when a conjunction is sensible, and this computation may be beyond the ability of 5-year-olds. The assessment of truth values during reasoning may also depend on different mechanisms than assessing the notion of possibility (Barrouillet, Gauffroy, & Lecas, 2008). It is therefore possible that using more naturalistic methods that do not demand reasoning or explicit evaluation would reveal awareness of inconsistencies at earlier ages.

Our findings suggest several additional paths for future work. Such work could examine usage corpora or use training procedures to determine how exposure to different types of true and false conjunctions relates to the comprehension of inconsistencies. It could also identify the role of domain knowledge in assessment of inconsistency. Our experiments were designed to require minimal domain knowledge; however, such knowledge may be important, and recent findings suggest that young children's errors in distinguishing impossible from improbable events may be due to limits in their domain-specific knowledge related to these events (Shtulman & Carey, 2007). Beyond clarifying the relative role of knowledge and experience, it would also be important to understand whether competence with tasks similar in complexity co-varies with children's competence with NSBIs and SBIs. These tasks may include transitive inference and class inclusion that necessitate representing common elements with different relations.

To summarize, our studies show that understanding inconsistencies appears to rely on two sorts of competence: the ability to appreciate that two situations are contradictory and the ability to represent the negated predicate in this context. Our findings thus suggest that the ability to represent two states of affairs is a precursor to understanding inconsistencies whose syntax is diagnostic of inconsistency. This is not to say that at some point children and adults are not aware of the schematic structure underlying SBIs; intuition suggests this is clearly the case. Yet, our data are most consistent with an explanation on which acquiring the ability to understand inconsistencies relies on the construction of semantic models rather than on acquiring sensitivity to any particular syntactic structure.

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