Cognitive Development, 4, 141–176 (1989)

Linguistic and Logical Factors in Recognition of Indeterminacy

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People, especially children, have difficulty recognizing cases of logical indeterminacy, that is, when no conclusion is logically warranted by the available evidence. This article examines the contribution of logical and linguistic factors to this phenomenon. Three experiments were conducted with second- and third-grade children. In each, subjects were given an initial premise sentence that partially described a set of invisible objects. Subjects were then presented with probe sentences referring to the objects and asked to tell whether each probe statement was logically true, false, or indeterminate given the premise. The first experiment examined two linguistic factors: the lexical embodiment of the relevant logical information in the probes (modal verb vs. copula), and the discourse level of the response (question-answering vs. truth-value judgment). Neither variable significantly reduced the difficulty of recognizing indeterminacy, indicating that, contrary to recent speculations, the logical form of the inference, rather than other linguistic aspects, is implicated in their difficulty. The next two experiments examined whether a task variable designed to reduce the complexity of the inferential process (while leaving the initial mental representation of the problem unchanged) would improve recognition of indeterminacy. This variable was highly

This work was supported in part by Grant 80-21459 from the National Science Foundation and in part by Grant 16-99925-01 from the Spencer Foundation, both to the first author. Preparation of the manuscript was also supported in part by a grant from the James S. McDonnell Foundation to Princeton University and by a Faculty Development Grant from Clark University. The first author gratefully acknowledges the hospitality of the Princeton Cognitive Science Laboratory and the Princeton Psychology Department during the 1987–88 academic year. Cooperation from the Worcester Public Schools Administration and from the principals and teachers of May Street, Lee Street, Tatnuck, and West Tatnuck schools is gratefully acknowledged.

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Manuscript received December 28, 1987; revision accepted May 18, 1988

effective, most importantly so in subjects with a fragile understanding of indeterminacy. It is argued that logical knowledge has both a representational and an executive function: It operates in generating the initial representation of the logical information, and in the executive monitoring of the subsequent inferential process. The difficulty of indeterminate inferences is task-dependent in its degree and presumably due, to a large extent, to the executive factor.

In reasoning situations, an individual must know not only how to arrive at a logically valid conclusion, but also how to identify cases in which no conclusion is logically warranted by the available evidence. Recognizing that the information given is insufficient for determining that a conclusion is necessarily true (as opposed to factually true and as opposed to plausible) is the touchstone of logical inference, as opposed to other kinds of ecologically valid inferences. It is not until recognition of logical indeterminacy is achieved that a person can be ascribed a conceptual understanding of logical necessity.

It has been a pervasive finding across a range of deductive tasks that indeterminate inferences are difficult, particularly for children but, in some tasks, also for adults: People often treat those inferences as if they led to a definite conclusion. The status of this collective finding is not entirely clear. A number of theoretical accounts of different kinds have been offered to explain it. For children at least, a basic cognitive phenomenon appears to be implicated, but, as will be discussed shortly, it seems to be juxtaposed with various task-specific phenomena, and the boundaries between those two factors are not always evident. For adults, the literature has been lopsided towards one specific kind of task, that is, conditional reasoning, as will also be discussed.

This article focuses on recognition of indeterminacy by children. It aims at understanding the *interplay* between logical factors and other relevant components of the reasoning process in those judgments. General questions regarding the organization of logical functions underlie our analysis. It is assumed that logical knowledge has both a representational and an executive function: It is involved both in generating the initial representation of the logical information, and in the executive monitoring of the subsequent deductive process (see Falmagne, 1985, for a more general discussion of those notions). Questions regarding the contribution of each of those aspects to judgments of indeterminacy dictate the design of the studies reported here and the interpretation of results.

DIFFICULTIES OF INDETERMINATE REASONING

A wide range of results has documented children's difficulties in recognizing indeterminate states of affairs. Children had difficulty recognizing that given several possible spatial routes to a goal location, the route actually taken was undecidable (Champaud, 1985); difficulty recognizing that given several possible sources of component parts for a constructed object, the actual source of parts was uncertain (Pieraut-Le Bonniec, 1974/1980); difficulty recognizing that given a statement about the size but not the color of geometric figures, subsequent judgments of size are determinate but judgments about color are indeterminate (Falmagne, 1975b); and difficulty in other generally analogous situations (e.g. Somerville, Hadkinson, & Greenberg, 1979).[1]

In addition, numerous results have documented the difficulties of indeterminate reasoning, both for children and adults, in verbally stated conditional *(if–then)* inferences and their quantified counterparts (e.g. Kodroff & Roberge, 1975; Revlis, 1975; Sternberg, 1979; Taplin, Staudenmayer, & Taddonio, 1974; Wason & Johnson-Laird, 1972). Factors specific to conditional relations, as well as more general factors, seem to be implicated in those findings. On the specific, "conditional" level, one focal issue in interpreting those responses, has been the lexical ambiguity of the *if–then* connective in natural language. The connective can yield either a conditional *if* or a biconditional *if and only if* interpretation; statements that are indeterminate on the conditional interpretation are determinate on the biconditional interpretation. Selection of the interpretation would be governed by presuppositions associated with the content of the statements, or by conversational conventions (e.g. Braine & Rumain, 1983; Fillenbaum, 1977; Legrenzi, 1970; Rumain, Connell, & Braine, 1983).

However, whatever the case for adults, children's difficulties with conditional relations seem to be deeper than what an account exclusively based on lexical ambiguity would explain. Considerable difficulty with indeterminate conditional inference has been evidenced by children of comparable ages in tasks in which the initial, conditional information was conveyed entirely nonverbally, via the properties of a certain visual display (Champaud, 1984; Champaud & Jakubowicz, 1983). Thus it is clear that, across a range of verbal and nonverbal logical tasks, children tend to be "determinate" in their responses to inferential situations.

EXISTING THEORETICAL ACCOUNTS AND THEIR RESPECTIVE TERRITORIES

Various kinds of accounts, at various "grains" of analysis, have been proposed to account for this phenomenon. One account focuses on response factors rather than on logical factors having to do with the indeterminate status of the referent state of affairs. It has been suggested that children may have a response bias against the response *can't tell* required for those indeterminate inferences (e.g., Braine & Rumain, 1983), putatively because it is unfamiliar, unusual in many

[1]Inhelder and Piaget (1955/1958) have also provided ample documentation about comparable difficulties in pre-adolescent children. However, as argued in Falmagne (1975a), their tasks involve children's thinking in a scientific rather than in a linguistic deductive paradigm, and therefore involve other factors aside from the purely deductive factors of interest here.

pragmatic contexts, and furthermore discouraged in school settings. If this account is correct, some of the results previously mentioned would be partly ambiguous because the task instructions may not have sufficiently stressed the response *can't tell* as an acceptable alternative.

In contrast, general cognitive factors have been proposed that may underlie children's problems with indeterminacy. It has been hypothesized that children's behavior was related to their conceptions of what is accepted as conclusive evidence (Bereiter, Hidi, & Dimitroff, 1979), to a reluctance towards "acceptance of lack of closure" (Wollman, Eylson, & Lawson, 1979), or to an "epistemic attitude" (Champaud, 1984) biased towards certainty.

Piagetian analyses claim that developmental changes in the distinction between determinate and indeterminate situations involve a global restructuring of the totality of cognitive operations (Inhelder & Piaget, 1955/1958; Kuhn, 1977; Piaget, 1983/1987), resulting in the construction of the correlative concepts of logical necessity and logical indeterminacy.[2] Analogously, although from a different theoretical perspective, Pieraut-LeBonniec (1974/1980), in a study of modal thought, argues for a long developmental process leading to the formation of genuine concepts of logical necessity and logical possibility: Modal notions initially would structure pragmatic action situations and finally attain logical ("alethic") forms of modality, in which the modal categories of necessity, contingency, and impossibility apply to propositions about states of affairs.

At a finer grain of analysis, focusing on the deductive process itself in sentential logic inferences, Braine and Rumain (1983) and Braine, Reiser, and Rumain (1984) speculate that children use natural logic schemata to derive determinate conclusions in that inferential domain, but that they may lack strategies for proving undecidability. Thus *undecidable* responses would result from a failed search for a valid conclusion, rather than resulting from attempts to establish indeterminacy directly.

Alternatively, in a different task domain, similar to that described in this article, Falmagne (1975b) speculates that judgments of indeterminacy resulted from a quasi-combinatorial analysis of a set of alternatives. The failures of those judgments, on this account, were due to premature termination of the combinatorial search. Furthermore, it appeared that the initial representation of the premise, while sufficient to generate judgments of *true* and *false* to the determinate inferences, had to be unfolded into a more detailed representation for judgments of indeterminacy. Thus, on this account, one factor in the increased difficulty of indeterminate inferences would be the additional mental steps involved and the greater complexity of the deductive procedures (these notions will be developed later in this article, in relation to Experiments 2 and 3).

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[2]It must be kept in mind, however, that the task domain from which those conclusions were drawn required reasoning in "scientific" contexts, thereby involving processes which overlap but do not coincide with the processes involved in the purely deductive situations considered here. For elaboration of this point, see Falmagne (1980).

It is useful to distinguish the claims made in those various accounts, as their difference in scope entails different levels of description of cognitive phenomena. Piagetian theory, as well as the theoretical notions on the development of modal reasoning proposed by Pieraut-Le Bonniec, describe global reorganizations of cognitive systems. These theories do not imply that pre-adolescent children are incapable of judgments of indeterminacy. Rather, they imply that the meaning of those responses (when children do give them) changes as the relevant cognitive system undergoes reorganization. These theories also specify the kinds of materials (''concrete'' in the case of Piaget, ''pragmatic'' in the case of Pieraut-Le Bonniec) with which children—specifically 7- to 9-year-olds—are equipped to recognize indeterminacy (at least sometimes).

While it seems reasonable to suppose that a cognitive phenomenon of a general nature is implicated in the difficulty of indeterminate inferences, it is likely that the difficulty is governed by complex determinants. Thus a useful research strategy is jointly to acknowledge general cognitive trends and to examine the operation of relevant task variables within those trends. For this reason, the target age in the studies to be described was 7 to 9, the population that appears most variable in the variety of the tasks used previously.[3] Since children's thinking is undergoing rapid development, the relevant processes can be expected to be sensitive to task variations. Alternative versions of simple tasks can be sensitive enough measures of cognitive behavior to provide insights about the various ingredients of the reasoning process and about their interplay. So, while acknowledging general cognitive factors and global developmental trends, the questions addressed in this article are formulated at a finer grain of analysis. We examine the contribution of logical representational factors and of logical executive factors to the recognition of indeterminacy, as well as the potential contribution of extra-logical factors (such as a response bias against *can't tell*).

FRAMING THE QUESTIONS

Specifically, we aim to assess: (a) to what extent the difficulty is related to the *logical form* of the inference (i.e., to the properties of the referent situation), as opposed to other aspects of the reasoning process, such as the particular linguistic embodiment of notions of possibility, the discourse form and surface syntactic form of the probe statement, or the overt response *can't tell* (Experiment 1); and (b) whether those difficulties that are properly logical are primarily representational deficiencies or whether they implicate executive factors tied to the complexity of the mental procedure required; thus, Experiments 2 and 3 will examine whether probes designed to simplify the mental procedure leading to answers without altering the logical structure of the problem, would enable

[3]Children under 6 years old have appeared incapable of recognizing or expressing indeterminacy in any of the paradigms used previously.

children to identify indeterminacy more successfully than has been the case standardly.

The present experiments, as well as those reported in Falmagne (1975b), employed a nonconditional paradigm, in order to dissociate questions regarding indeterminate reasoning per se from those more specifically linked to the lexical ambiguity of conditional connectives. Furthermore, as will be described later, the experiments were designed to eliminate lexical ambiguities, by probing the child's spontaneous mode of expression for the target information. Finally, in contrast to the procedure used in a number of previous studies in the literature, the instructions were forceful in stressing the legitimacy of the response *can't tell* ("Sometimes, the most intelligent person in the world would have no way of knowing whether it is true or false, because I just didn't tell you enough about the situation"), and provided examples from a different domain illustrating each of the three response choices, in order to counteract the assumption that questions must be given a determinate, *yes* or *no* answer. Those measures presumably ensure that factors related to lexical ambiguity and to communicative biases are eliminated, and that the logico-linguistic phenomenon of interest is tapped relatively directly.

EXPERIMENT 1

Experiment 1 examines the contribution of two linguistic factors to children's recognition of indeterminacy. This experiment is motivated by general questions concerning the ways in which the mode of expression of logical relations affects the representation and processing of those relations. A first question concerns the linguistic embodiment of indeterminacy. Indeterminacy may find its expression either extrapropositionally, through judgments of *indeterminate* about the truth value of a proposition, or intrapropositionally, through the use of modal terms (e.g., *can, may, has to, necessarily, possibly*). The majority of the reasoning studies mentioned uses the former kind of formulation; in everyday reasoning, however, modal terms rather than propositional judgments are the prevalent vehicles for expressing the concepts of logical necessity, impossibility, or indeterminacy (contingency, possibility).[4]

Several reasons converge to suggest that the latter, modal mode of expression may reduce the difficulty of judgments of indeterminacy. First, lexical reasoning has generally been found to be faster and smoother than propositional reasoning, possibly because a considerable amount of logical information is encoded lexically and via meaning relations between lexical items (see, e.g., Johnson-Laird,

[4]Pieraut-Le Bonniec's (1974/1980) experiments did use modal language in at least some of the probes; however, several of the task situations in effect require the subject to generate the relevant description of the premises on which deductive processes can then operate. This certainly increases the cognitive complexity of the task as compared to others, and renders direct comparisons difficult.

1977, 1983), and possibly because, unlike propositional reasoning, lexical reasoning does not entail judgments *about* propositions and hence of a metalinguistic nature. Secondly, modal terms provide a more direct and more transparent mapping between the statement and its (indeterminate) logical form, when the statement is indeed indeterminate (see Falmagne, 1980, for a discussion of the importance of this factor). Finally, given that lexical expressions of indeterminacy are indeed more frequent in everyday contexts, the usual assumptions regarding the use of cognitive skills (Anderson, 1981) would lead one to expect that lexical reasoning skills associated with indeterminacy may be more spontaneously accessed and more easily deployed.

These considerations suggest that the findings obtained previously might be due, at least in part, to the unnaturalness or indirectness of the extrapropositional probes used. It is important to assess indeterminate reasoning processes through the presumably more direct and more familiar formulation, in order to determine the relative contribution of linguistic and of strictly logical factors to the recognition (or absence thereof) of indeterminacy.

The tasks were similar to those used in Falmagne (1975b): Children were shown an array of cards depicting geometrical figures of various sizes and colors. The experimenter then took away all the cards, placed some of them in a box, outside the child's view, and gave the child partial information about the content of the box (e.g., "In this box, all the cards have big circles"). A list of probe sentences was then read to the child for evaluation; the child stated whether each given sentence was true, false, or indeterminate.

Two kinds of probe sentences were presented (in separate tasks). One condition involved propositions with the copula *is,* of the kind *In the box, there is a red circle,* as was the case in the previous studies. The other condition involved logically equivalent propositions phrased using modal terms, for example, *In the box, there can be a red circle; In the box, there has to be a red circle.*

In the light of previous discussions, the use of modal language has the additional advantage of yielding only two truth values (*true* and *false*), thus enabling one to dissociate the purely logical factors implicated in judgments of indeterminacy from the possible response factors associated with the response *can't tell.* Thus, in the example in the preceding paragraph, recognition of the indeterminacy of the referent situation is manifested by answering *true* to the *can* proposition, and *false* to the *has to* proposition, in contrast with the logically comparable "copula" proposition, which calls for a *can't tell* response.

Thus, difficulties resulting strictly from a response bias against *can't tell* should be eliminated by the modal phrasing. In contrast, if the difficulty is of a logical nature and specifically related to the indeterminacy of the referent situation, it should persist under the modal formulation.

A second extra-logical linguistic factor was investigated in Experiment 1. It has been argued that truth value judgments are difficult kinds of judgments, both because they are unfamiliar and unnatural in everyday situations, which mostly involve ordinary discourse operations (e.g., Braine & Rumain, 1983; Pieraut-Le Bonniec, 1980, p. 61; and, by implication, Luria, 1976; Scribner 1977), and, in the case of children at least, because they constitute metalinguistic judgments, which are held to be difficult for young children (Gleitman & Gleitman, 1979; Hakes, 1980; Smith & Tager-Flusberg, 1982). If there is an intrinsic difficulty in judgments of indeterminacy, it is likely to be amplified by the requirement for the child to give that judgment in the form of a truth value judgment. Thus, Experiment 1 also assessed whether altering the task so as to ask children questions about the potential content of the box, rather than presenting propositions for truth value judgment, would reduce the relative difficulty of indeterminate inferences, since answering questions presumably involves discourse-level operations only. A pair of comparable items in the two respective tasks are, for instance, *In this box, is there a red circle?* and *In this box, there is a red circle.* The first probe calls for an answer *can't tell* to the question; the second, for a judgment of indeterminacy (*can't tell*) about the proposition. Summarizing, Experiment 1 examined two linguistic factors: lexical formulation (modal vs. copula) and discourse level (question vs. proposition). The factors were crossed in a within-subjects design.

Methods

Subjects. Subjects were 24 second- and 18 third-grade children from Worcester, Massachusetts, public schools attended primarily by working and middle-class families. Second-graders ranged in age from 7 years, 7 months to 9 years, 3 months at time of testing, with a mean age of 8 years, 2 months. Third-graders ranged in age from 8 years, 5 months to 10 years, 1 month, with a mean age of 9 years, 1 month. Parents of participants were given $4.00 to defray transportation costs.

Materials and Design. Children were tested individually at Clark University Child Laboratory in a single session lasting approximately 45 min. Each child was given four inference tasks at a few minutes' interval. Each task consisted of an initial premise, stated by the experimenter about a referent situation, and a list of probe statements about that situation; for each probe statement, the child was to respond whether the statement was true, false, or indeterminate, given the premise. The four tasks were logically identical, but each task involved a different initial premise, and a different linguistic formulation of probes, as described below.

The physical materials that composed the reference set for all the tasks were eighteen 3 × 5-in. white cards, each with one circle painted on it. The circles were of three sizes (small, medium, and big) and three colors (red, blue, and yellow). Two cards of each of the nine size–color combinations were included. The other physical material was a 3 × 5 × 4-in. covered box into which the cards could be placed.

The initial premise statements for each of the four tasks gave the child partial information about the specific subset of cards that was in the box for that task. The premise was given verbally, and was of the general form *In this box, all the cards have big circles,* (e.g.) or a paraphrase of this formulation, whichever stylistic variant the child found easiest to understand, as assessed previously (see "Procedure"). The dimension (size or color) and the value along the dimension that was mentioned in the premise (e.g., "big" vs. "small") varied across tasks.

In each of the four tasks, after the initial premise was given, a list of probe sentences was presented to the child verbally, one at a time, for evaluation. The four tasks differed by the lexical formulation of the probes (modal vs. copula) and the discourse level of the probes (propositions vs. questions), with each task consisting of one combination obtained from crossing those two factors. Thus, the probe lists in the four tasks were composed respectively of: (a) propositions with the copula *is,* for example *In the box, there is a red circle;* (b) questions with the copula *is,* for example *In the box, is there a red circle?*; (c) modal propositions, for example *In the box, there can be a red circle; In the box, there has to be a red circle;* and (d) modal questions, for example *In the box, can there be a red circle? In the box, does there have to be a red circle?*

Each task list included equal numbers of sentences that were true, false, and indeterminate. The copula tasks included two sentences in each response category; one existentially quantified (e.g., *There is a red circle*) and the other universally quantified (e.g., *All of them are red circles*). The modal tasks included four sentences in each response category, that is, two existentially quantified sentences with one sentence including the operator *can* and the other including the operator *must* (e.g., *There can be a red circle; There has to be a red circle*), and two universally quantified sentences (one *can* and one *must*). Response choices for the copula tasks were *true, false,* and *can't tell* for propositions, and *yes, no* and *can't tell* for questions. Response choices for the modal tasks were *true* and *false* for propositions, and *yes* and *no* for questions.

As an example, consider the copula proposition task with the premise *In the box, I only put big circles.* The task list had six sentences. Two were determinate true, for example *In the box there is a big circle* and *In the box, all of them are big circles.* Two were determinate false, for example *In the box, there is a small circle* and *In the box, all of them are medium circles.* Two were indeterminate, for example *In the box, there is a red circle* and *In the box, all of them are yellow circles.*

The order of tasks was counterbalanced across subjects. The specific dimension (size or color) or value (e.g., big or small) used in the premise was different for each task for a given subject, and the pairing of dimension and specific value with task was counterbalanced across subjects. Within each task list, the order of sentence presentation was randomized, with the exception that the first three sentences presented always included one of each of the determinate true, determinate false, and indeterminate types.

Procedure. Before the main inference tasks were given, a pretest was administered to determine the child's preferred description of referent situations analogous to that described by the premise in the main tasks. In the pretest, the child was told that a game would be played later and that the experimenter wanted the child to help make the rules easy to understand. The experimenter displayed 18 cards, half with letters painted on them, half with geometric figures on them. Then, *within* the child's view (unlike the procedure in the main tasks), the experimenter placed two thirds of the letter cards in a box, and asked which description of the situation the child thought was easiest to understand: (a) "All the cards in the box are letters," (b) "I only put letters in the box," (c) "I put nothing but letters in the box." The child's choice of stylistic variant (*all, only, nothing but*) was used subsequently throughout the main tasks for that child.

Following the pretest, the child was told that a question-and-answer game was to be played as follows. The child would be told something at the beginning of that game, and was to remember it and use it to figure out the answers. Instructions stressed that the initial information was all that was needed to figure out the answer, and that the child was not to use anything else. Sometimes the answer would be *yes* (or *true* for the propositional tasks), and the child could tell that it was definitely *yes* using just what he or she was told at the beginning. Sometimes the answer would be *no* (or *false* for the propositional tasks), and the child could tell that it was definitely *no* using what he or she was told at the beginning. Sometimes there would be no way for the child to tell whether the answer is *yes* or *no,* and "not even the smartest person in the world could tell," using just what the child was told at the beginning. In that case, the child was to answer *can't tell.* Following the above instructions, six training sentences were given to familiarize the child with the three kinds of responses and the latency recording procedure.

For each of the four tasks the 18 colored circles were displayed and described by the experimenter. Then the child turned away while the experimenter put some of the cards in the box and the remaining cards face down in a single pile. The experimenter then gave the premise, repeated the rules and responses for the given task, asked the child to repeat the premise, and began presenting the sentences for evaluation. Latencies were recorded with an electronic timer operated manually. The experimenter started the timer at the end of the sentence presentation, and the child stopped the timer simultaneously with the verbal response.

Results

Most of the error data to be discussed concern indeterminate inferences. (Performance on determinate inferences was virtually errorless in all tasks.) Henceforth, the term *indeterminate inference* is used for probes (propositions or questions) *referring to* an indeterminate situation. It will be important to keep in mind that those inferences call for different responses in the copula and the modal tasks, respectively. In the copula tasks, a *can't tell* response is called for. In contrast, in the modal tasks, only two truth values (true and false) are defined, and indeterminate inferences (i.e., inferences referring to an indeterminate situation) call either for a *true* (or *yes*) response, or for a *false* (or *no*) response; thus, their surface structure and their response are similar to those of determinate inferences. For instance, given the premise *In this box there are only big circles,* the proposition *In the box, there can be a big circle* is true and refers to a determinate situation, whereas the proposition *In the box, there can be a red circle* is true (because of the modal predicate *can*) but refers to an indeterminate situation.

The main questions addressed in this experiment concerned the comparison between indeterminate inferences with modal terms and logically equivalent inferences expressed in copula (non-modal) form, and the comparison between truth-value judgments and question-answering. Before turning to those issues, an examination of the individual patterns of responses to the set of indeterminate inferences will prove useful for two reasons: to assess the consistency of responses within tasks, and to inform the analyses discussed in subsequent sections.

Individual Patterns of Responses. Each copula task includes two indeterminate propositions (or questions). Each modal task includes four indeterminate propositions (or questions). Within each task, the configuration of responses given by a child to the set of indeterminate items falls into three categories. Those are schematized in Table 1 for convenience, for the premise *In this box, there are only big circles:* (a) the configuration indicating that, for that task, the

Table 1. Types of Individual Patterns of Responses to Indeterminate Propositions, for the Premise *In this box, there are only big circles*

	Pattern		
Proposition Task	**IND**	**DET**	**OTHER**[a]
Copula (Non-Modal) Task			
. . . there is a red circle	CT	T	F
. . . all of them are red circles	CT	F	F
Modal Task			
. . . there can be a red circle	T	T	T
. . . there has to be a red circle	F	T	T
. . . all of them can be red circles	T	F	T
. . . all of them have to be red circles	F	F	F

Note. The responses *true, false,* and *can't tell* are symbolized as T, F, and CT, respectively. An identical table for the Copula Question and Modal Question tasks can be obtained by transforming the propositions into question form and by substituting *yes* and *no* for *true* and *false,* respectively.

[a]One example of a specific OTHER pattern is shown (among other possible instances).

indeterminate reasoning; the correct response in the OTHER task would result from a genuinely correct reasoning process. Under this hypothesis, these latencies should vary as if they were part of an IND pattern, that is, should be longer than those of true and false inferences. The relevant data are presented in Figure 2, separately for OTHER patterns occurring in conjunction with a DET pattern in the twin task, and for OTHER patterns occurring in conjunction with an IND pattern.

Several observations are of interest (keeping in mind, however, that the number of observations contributing to that figure is small: 11 to 28 observations per bar). First, for both data sets, the latencies of correct responses to indeterminate inferences are much longer than the latencies of true and false inferences; this suggests that even the OTHER task associated with a DET task does indeed reflect an underlying (though prone to error) indeterminate mode of reasoning. Second, crucially, the latencies of *errors* to indeterminate inferences are very long also, suggesting again that these errors stem not from a deterministic representation, but from a flawed attempt to pursue an indeterminate mode of reasoning. This is particularly striking when contrasted with the DET responses in

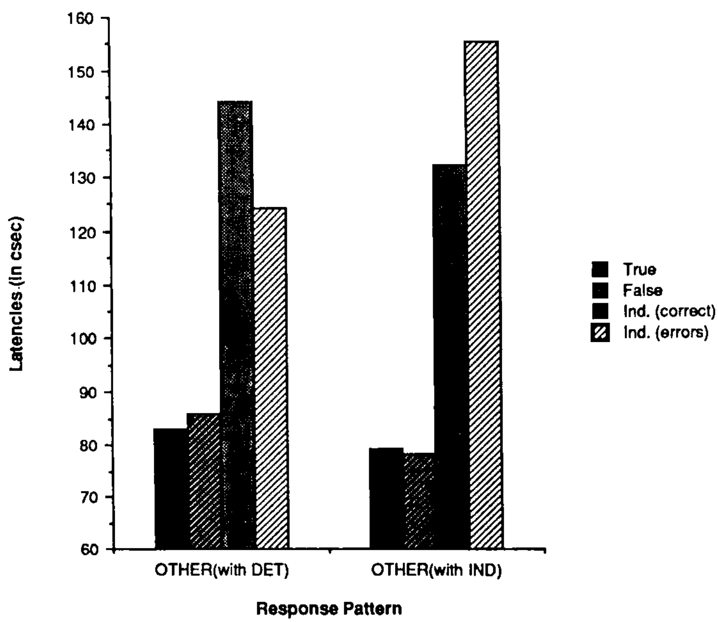

Figure 2. Experiment 1: Mean latencies of correct responses in the OTHER task, respectively, when it is associated with an IND task and when it is associated with a DET task; and mean latencies of errors (see Table 1 for definition of IND, DET, and OTHER)

Figure 1, most of which were errors, whose latencies were virtually identical across all three response categories.

Thus this entire configuration of results strongly suggests that OTHER patterns of responses are generated from an indeterminate representation of the problem, but that this representation is too fragile to sustain the required deductive process consistently. As an additional result consistent with this point, it is interesting to note that the mean correct latencies to indeterminate inferences in the OTHER task are longer than those displayed in Figure 1 for IND tasks (132 csec vs. 102 csec), which seems to suggest a greater temporary difficulty in pursuing the indeterminate mode of reasoning. This is, of course, also consistent with the fact that errors do occur in this OTHER task.

To summarize, the results so far indicate that two modes of representation of the premise are being used (deterministic and indeterminate), with the OTHER patterns of responses resulting from a fragile indeterminate representation.

Comparison between the Modal and the Non-Modal Tasks. In order to compare the error rates in the copula and modal tasks, some restructuring of the raw data is required, as follows: A given modal task includes two pairs of indeterminate items (e.g., as one pair, *There can be a red circle; There has to be a red circle;* and, as the other pair, *All of them can be red circles; All of them have to be red circles*). A child must jointly answer *true* to the *can* proposition of a given pair and *false* to the *has to* member of that pair if (s)he is to be assessed as having carried out the correct indeterminate inference. In fact, each modal pair logically corresponds to one single proposition in the copula task (e.g., *There is a red circle—can't tell,* in the example above). Thus, a correct representation of indeterminacy entails answering correctly to *both* members of the pair and, therefore, the meaningful unit of data analysis is the modal pair, not the individual proposition. Another way of looking at this situation is that, of the four modal indeterminate inferences, two can be answered correctly either from a correct, indeterminate mode of reasoning, or from a deterministic mode of reasoning, as can be verified from Table 1. Thus a percent correct computed over the four single propositions would be misleadingly inflated as an index of correct reasoning. The analysis of pairs of responses avoids this pitfall.

For the purpose of comparison, the responses to determinate modal sentences were scored as pairs as well, although this was not required conceptually in that case. Since performance on those inferences was virtually errorless, this manipulation had little quantitative effect.

Table 2 displays the percent of correct responses in the copula (non-modal) tasks and the percent of correct pairs in the modal tasks. A preliminary observation is of interest: In the modal tasks, performance for response pairs to the true or false items is almost errorless. This indicates, in particular, that there is no intrinsic surface comprehension problem associated with the modal forms *can* and *have to* in children of that age and that whatever difficulty occurs (as will be

Table 2. Percentage of Correct Responses in the Copula (Non-Modal) Tasks and of Correct Pairs of Responses in the Modal Tasks[a]

Inference Form	Response Category		
	True	False	Indeterminate
Modal Tasks			
Propositions	95	95	48
Questions	90	96	43
Copula Tasks			
Propositions	96	99	38
Questions	97	97	40

[a]See text for description of the scoring of modals.

seen shortly) is due to the logical properties of the referent situation rather than to surface lexical factors.

Clearly, for both the modal and the copula tasks, performance to indeterminate items is much lower than for determinate items ($z = 5.45$, $p < .001$ for modals; $z = 6.52$, $p < .001$ for copulas; Irwin-Fisher test, large sample approximation, Marascuilo & McSweeney, 1977). Hence, the difficulty of indeterminate inferences remains under the modal formulation. It is important to remember that in the modal task those indeterminate propositions and questions call for the same responses, *yes* or *no,* as the determinate items. Thus, the difficulty of indeterminate items in this task is specifically due to the indeterminacy of the referent situation, as opposed to any possible response bias component against *can't tell.*

Furthermore, the percent correct is similar in the modal and the non-modal task. Although it appears to be slightly higher in the modal task, this difference is not significant ($z = .60$). Thus, the two tasks are of approximately equal difficulty.

However, the two tasks are not indifferent psychologically. Examination of individual patterns of responses suggests that the modal task may be more conducive to correct reasoning for those subjects who display a fragile understanding of indeterminacy. If one examines the joint pattern of responses to the two copula tasks or to the two modal tasks, it appears that the frequency of IND–IND configurations is equivalent for modals and copulas, and so is the frequency of DET–DET configurations, but that the modal tasks display more frequent IND–OTHER configurations than the copula tasks (14 vs. 4, respectively), and, conversely, display fewer DET–OTHER configurations (3 vs. 9, respectively). Thus, the modal formulation appears to affect those configurations that reflect a less stable mode of reasoning, that is, those subjects who are neither solidly "deterministic" nor solidly "indeterminate."

Comparison between the Proposition and the Question Tasks. The comparison between propositions and questions regarding overall percent of correct responses (or correct response pairs) can be made by returning to Table 2. Clearly, there is no difference between the two forms in that regard. An examination of individual patterns of responses also reveals no difference between propositions and questions.

However, the latencies of responses to inferences in those two respective forms show a consistent difference, as presented in Figure 3 for correct responses: The latencies of responses to propositions are longer. A 2 × 3 (Inference form × Response category) ANOVA on mean latencies of correct responses showed this difference to be significant; F (2, 41) = 7.4, $p < .01$. This difference holds for the error latencies as well: The means are 115 versus 88 csec, for propositions and questions, respectively.

This difference is interesting in view of the speculation advanced in the introduction to this article, according to which the truth judgments required in the proposition tasks are judgments of a metalinguistic kind in contrast to the process required for question answering in the (logically equivalent) question tasks, which is presumed to take place at the usual discourse comprehension level. We will return to this point in the final discussion.

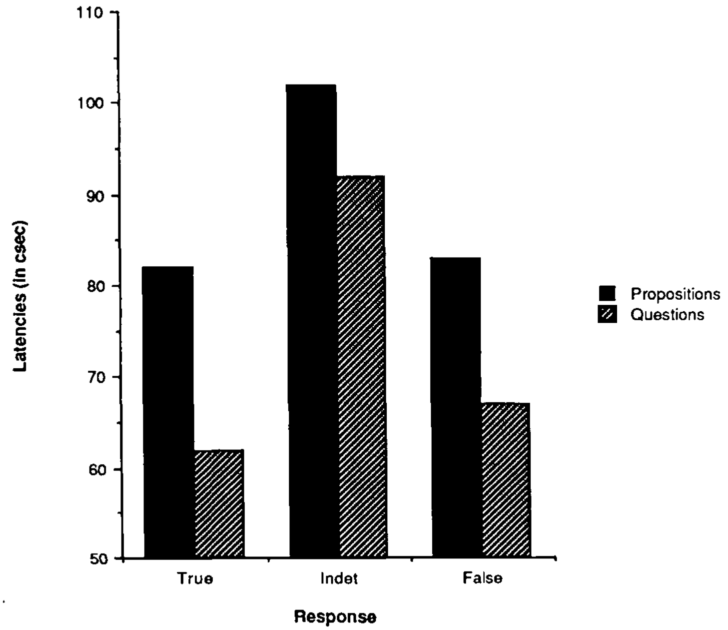

Figure 3. Experiment 1: Mean latencies of correct responses to propositions and to questions for the true, false, and indeterminate inferences

Table 3. Percent Correct in Each Grade, for True, False, and Indeterminate Inferences

	Response Category		
Grade	True	False	Indeterminate
Modal Tasks			
Second	90	93	42
Third	94	100	53
Copula Tasks			
Second	97	97	34
Third	97	100	43
Propositions			
Second	97	95	40
Third	94	100	47
Questions			
Second	90	95	37
Third	97	10	48

Note. Values are % correct responses for copulas and % correct pairs of responses for modals.

Age-related Comparisons. The main results described so far hold for both second and third graders, namely, the equivalence of the modal and copula formulations regarding the difficulty of indeterminate inferences; the equivalence of propositions and questions in that same respect; and the significantly longer latencies of inferences phrased as propositions.

Table 3 presents the percent correct in each grade (Modals are scored as pairs, as explained previously). The older children perform better than the younger children on indeterminate inferences, although this difference is not significant. (Also of some interest is the fact that the latencies of inferences are longer for the younger children; in particular, the mean latencies of correct indeterminate responses are 119 csec in Grade 2 vs. 69 csec in Grade 3.)

In order to take a closer look at the locus of this age-related difference, the percentage of IND, DET, and OTHER patterns of responses in each grade are

Table 4. Percentage of IND, DET and OTHER Patterns of Responses per Task in Each Grade

	Pattern		
Grade	IND	DET	OTHER
Second	28	41	31
Third	39	42	19

Note. IND, DET, and OTHER are indeterminate, determinate, and other response patterns, respectively (see Table 1).

presented in Table 4. Interestingly, the percentage of DET patterns remains constant over both grades; the main trade-off is an increase in IND patterns between Grades 2 and 3 and a corresponding decrease in OTHER patterns. Thus, here again, OTHER patterns appear to play a transitional role and perhaps reflect a fragile understanding of indeterminacy. The primary difference between the two age groups would lie in a consolidation of this understanding.

Discussion

Effect of the Linguistic Embodiment of Indeterminacy. The aim of this experiment was to assess to what extent linguistic factors other than logical form per se contributed to the difficulty of judgments of indeterminacy. Our question was whether the particular difficulties of indeterminate inferences might be reduced when uncertainty is encoded lexically via modal language. The results show that this is not the case, since modal phrasing did not significantly reduce the difficulty of indeterminate inferences.

One additional, important implication of this result is that the difficulty of indeterminate reasoning is not due to response factors, specifically to the unfamiliarity of the response *can't tell,* as hypothesized by Braine and Rumain (1983) among others. Since the modal task only requires *yes* and *no* responses, that conjecture is ruled out entirely by our results. Thus, the difficulty of indeterminate inferences is, according to our results, genuinely due to the indeterminacy of the referent state of affairs.

Here, it is important to remember that the premise given to each child was that formulation (*only, all, nothing but*) that the child had selected previously as being the clearest description of the referent situation (see "Procedure"). Thus, it is not the case that children failed to understand the terms and that errors are due to this lexical ambiguity. Rather, the results described do constitute a genuine deductive phenomenon. Perhaps some children's logical understanding of the relevant expression in the premise was fragile, so that the expression could be used correctly in the presence of the referent situation (as in the pretest), but not as a vehicle for inference (as in the main task).

Interestingly, while the modal formulation does not eliminate or significantly decrease the difficulty of indeterminate inferences, the two formulations are not indifferent psychologically. Specifically, the modal formulation led to a surplus of mixed IND–OTHER patterns of responses, while the non-modal formulation led to a surplus of DET–OTHER patterns. (This result is congruent with the error data just mentioned, but not strictly implied by it since other, nonsystematic response patterns could have led to the same percent correct.) Since various analyses led us to interpret OTHER patterns as flawed attempts to pursue indeterminate reasoning, it seems that the modal task may be a more sensitive test for children who are transitional.

Summarizing, our data indicate that the modal–copula variable is cognitively relevant, but does not affect the overall difficulty of indeterminate judgments.

Effect of the Discourse Form of Inferences. The second central result is that the discourse form of inferences, that is, propositions requiring a truth value judgment of indeterminacy (*can't tell*), versus questions requiring a *can't tell* answer, did not affect performance. Thus, the difficulty of indeterminate judgments does not appear to be linked to the particular cognitive requirements of truth judgments, unlike what an a priori task analysis and previous speculations (e.g., Braine & Rumain, 1983) might have led one to suppose.

However, the two inference forms do differ psychologically since the latencies of correct truth judgments about propositions are longer than those of corresponding answers to questions. This is especially noteworthy considering that questions are presumably of greater syntactic complexity than their propositional counterparts, which are declarative sentences. This result, which holds for all three response categories, accords with an account of truth value judgments as metalinguistic judgments involving additional operations to those of discourse-level processing. An alternative interpretation is that truth value judgments are simply less familiar than question-answering. The two interpretations cannot be adjudicated on the basis of the present results. However, it is worth noting that this confounding is true of any result regarding metacognitive knowledge (e.g., Hakes, 1980): The metacognitive judgments required in those tasks are less practiced than the first order processing involved in the relevant everyday memory or language activities. While this observation evidently does not rule out the possibility of a simple familiarity effect as opposed to an effect specifically linked to the metalinguistic character of truth value judgments, the ambiguity does not seem greater than it is in the "metacognitive" literature.

Thus, as was the case for the modal–copula variable, the form of the inference does have psychological relevance, perhaps attributable to the metalinguistic nature of truth value judgments. Yet, those differences do not alter the difficulty of judgments of indeterminacy.

Transitional Responses as Flawed Attempts at Indeterminate Reasoning. Aside from those results directly related to the initial concerns of the experiment, an interesting set of results emerged concerning the psychological significance of the OTHER patterns of responses. These results deserve emphasis because they will be used in subsequent analyses in Experiments 2 and 3. First, as pointed out previously, the OTHER pattern is usually associated with a DET or an IND pattern in the twin task (rather than with a second OTHER pattern). This suggests in a preliminary way that the OTHER pattern is not due to random or unsystematic responding, but rather is a deviation from either a DET or an IND pattern. When examining latency data, it appeared, furthermore, that the OTHER patterns resemble the IND rather than the DET pattern in that respect—that is, exhibit the characteristic increase in latencies of responses to indeterminate items—and, importantly, that this increase held for both the correct and the erroneous responses. Additionally, the age-related trend between second and third grades was characterized by a shift from OTHER to IND patterns of responses, while the percentage of DET remained constant.

Thus, together the latency and age-related results support an interpretation of OTHER patterns of responses as reflecting a fragile IND representation for children in transition from a deterministic mode of reasoning to a mode of reasoning incorporating a stable understanding of indeterminacy. Furthermore, as stated previously, the configurations of responses including an OTHER pattern were affected by the changes in modal versus copula formulation, even though that variable did not have an overall effect: Thus, these configurations seem to be less stable and more easily controlled by task variations, which supports their interpretation as transitional response patterns.

Developmental Trends. Aside from an expected increase in overall accuracy, the older children were found to display more stable modes of reasoning within a given task. Specifically, they exhibited an increase in frequency of IND patterns, as mentioned previously, accompanied by a decrease in OTHER patterns. This, in addition to the fact that their latencies were shorter, seems to indicate that, even within this 1-year age span, a more stable representation of indeterminacy developed.

EXPERIMENT 2

While the previous experiment examined two factors of a strictly linguistic kind, the aim of Experiment 2 was to examine a variable involving the referential aspect of the probe sentences to be judged, specifically of the question probes. In contrast to the questions of Experiment 1, which involved quantified judgments (e.g., *In the box is there a red circle? In the box are all of them red circles?*), and therefore referred to the content of the entire box, the questions in this experiment were phrased so as to refer to a *single,* nonvisible object. Thus, for example, after stating the premise, (e.g. "In this box, there are only big circles"), the experimenter would open the box, keeping its contents hidden from the child and say "I am looking at a card. Is it a red circle?"

The aim was to create a situation logically equivalent to the previous ones, but designed to simplify the mental procedure required to generate the response, in order to examine the role of processing complexity in judgments of indeterminacy.

A general assumption about the organization of logical functions underlies this analysis. It is assumed (Falmagne, 1985) that logical knowledge has both a representational and an executive function: It is involved both in generating the initial representation of the logical information, and in the executive monitoring of the subsequent process. Thus, the entire program of deductive steps generated from the initial representation is monitored by the child's logical understanding of the problem. It is important to note that this is not a competence–performance distinction: The deductive steps generated from the initial representation are not seen as a performance component of the process; rather, on the present conception, the execution of the entire process is monitored by the logical executive function.[5] One implication of this conception is that development (and expertise) involves not only conceptual restructuring but also elaboration and strengthening of the executive control processes underlying deduction. Another implication is that if the initial understanding is weak, it may be insufficient to successfully monitor the execution of a complex deductive process, but sufficient to guide the execution of a simple process, even if the initial representation is unchanged. Those notions are elaborated in the discussion of results of this experiment and in the "Conclusions" section.

Previous results yield specific suggestions regarding the processing of quantified judgments and of single object judgments in this situation. In a previous model described in Falmagne (1975b) for a similar paradigm involving quantified judgments, it was assumed that two different modes of representation of the premise were involved in the determinate judgments and in the judgments of indeterminacy, respectively. The response process involved in determinate *true* and *false* judgments was assumed to utilize a schematized representation of the premise in the form of a single object, incompletely specified (e.g., in the example above, a big circle of unspecified color). In contrast, for propositions calling for a judgment of indeterminacy, it appeared that the schematized representation, though logically sufficient to yield the correct answer, was not being used, and that, instead, a more fully specified representation was being unfolded in the form of the collection of big circles of various colors, tagged as being tentative elements of the box; the response would be based on a (quasi) combinatorial analysis of that tentative set, the details of which are not relevant to the present matter. The assumption of two alternative modes of representation was based on the pattern of latency data, indicating that the latencies of indeterminate correct responses—but not those of true and false correct responses—were affected by the number of colors (in the present example) present in the referent material; if indeterminate judgments involved a representation of the premise in the form of a colorless big circle, such differences would not obtain.

It is possible that the need to rely on a fully specified representation of the premise, in the form of a set of tentative elements, was specific to quantified

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[5]Related notions have been discussed by Greeno, Riley, and Gelman (1984), who characterize competence as including a conceptual, a procedural, and a utilizational component. Thus, both these authors' account and the present account include the control processes in their characterization of competence. There are a number of differences between the two approaches, however. In particular, Greeno, Riley, and Gelman characterize procedural competence by means of a general planner, whereas on the present account the logical executive processes are themselves dependent upon the child's level of logical understanding. Furthermore, Greeno, Riley, and Gelman's account focuses on conceptual competence for a domain, described as consisting of action schemata representing principles for that domain, whereas the present account focuses on on-line semantic representations of specific premises (generated on the basis of the child's underlying logical knowledge).

inferences. One rationale for introducing questions bearing on a single invisible object in the present experiment was that perhaps these questions could be answered from the initial schematized mode of representation of the premise. Since that representation is simpler and since the corresponding response process does not involve the complex combinatorial analysis hypothesized for quantified inferences, it can reasonably be predicted to lead to a higher level of performance, if children have a weak understanding of indeterminacy. A more specific characterization of weak and strong understanding of indeterminacy in this situation, and of their consequences for the deductive process, will be provided in the discussion of results of this experiment.

Methods

Subjects were 10 second-grade and 10 third-grade children from public schools in Worcester, Massachusetts, attended by a predominantly middle-class population. The 20 children ranged in age from 7 years, 10 months to 9 years, 8 months, with a mean of 8 years, 10 months at time of testing. The materials, design, and procedure were the same as in Experiment 1, with the exception of the phrasing of the question items. In the question condition, after stating the premise for each task (e.g., "In this box, there are only big circles"), the experimenter took one card from the box saying, "I am taking one card out of the box and looking at it. All the questions I ask you will be about this one card that I am looking at." Then the sentences were presented. With a single reference card, only one kind of question was appropriate (e.g., *Is it a red circle?*) instead of the two questions *Is there a red circle? Are all of them red circles?* as was the case in the previous experiment. In order to facilitate comparisons with the results in Experiment 1, the number of questions presented was the same as in Experiment 1. However, it was undesirable to present specific questions more than once, because the child might construe the repetition as an invitation to alter the first response. Therefore, two modal question tasks and two copula question tasks were administered (with different premises).

Results

The main purpose of this experiment was to assess whether questions referring to a single invisible object would be easier to answer than quantified propositions and than the quantified questions of Experiment 1. The two age groups were included for comparability with the sample from Experiment 1, but since age was not a variable of interest in this experiment, the two age groups were pooled for purposes of analysis. Table 5 shows the percent correct for the propositions and the single object questions respectively (i.e., the percent of correct responses to copula inferences and of correct pairs of responses to the modal inferences).

It is clear that single object questions are easier than quantified inferences, and this holds for both modal and copula inferences ($z = 3.50$, $p < .001$ for modals; $z = 2.76$, $p < .005$ for copulas, Irwin-Fisher test, normal approxima-

Table 5. Percent Correct to Propositions and to Single Object Questions

Inference Form	Response Category		
	True	False	Indeterminate
Modal Tasks			
Propositions	95	98	30
Questions	100	100	85
Copula Tasks			
Propositions	93	98	50
Questions	98	98	90

Note. Values are % correct responses for copulas and % correct pairs of responses for modals.

tion). While all quantified inferences were propositions in this experiment, it should be remembered that no difference between quantified propositions and quantified questions was obtained in Experiment 1, so that the present result can be taken genuinely to reflect a greater ease of inferences referring to single objects.

Further probing is needed to assess the interpretation of this result unambiguously. Questions referring to a single object (e.g., *I am looking at something; is it a red circle?* in the case of the premise *In this box there are only big circles*) can be answered correctly on two different bases: One is to carry out the correct, indeterminate reasoning process, realize that one does not know the composition of the box color-wise and, therefore, a fortiori, the color of the target item. The other is to assume, incorrectly, that the box contains all the big circles (i.e., to hold a deterministic representation of the premise), yet to answer *can't tell* to the question since even with such a representation one does not know which particular circle the experimenter is presently looking at; therefore, in this case, the "correct" response is based upon the uncertainty of sampling of one object, even though the representation of the set of objects in the box is deterministic. Thus, it is in principle possible that the high percentage of correct responses to the questions in this experiment is due to the occurrence of the latter process.

However, two sets of results render this latter possibility extremely implausible. The first analysis consists in comparing the performance on question inferences for children who displayed a deterministic pattern of responses in the twin proposition task and for those children who did not display such a pattern. If the increase in accuracy in the question task is entirely due to the (theoretically uninteresting) occurrence of a deterministic representation accompanied by recognition of the indeterminacy of sampling, then the superiority of the questions should disappear for those children who are "nondeterministic."

The nondeterministic children can be further separated into those who display an IND pattern of responses and those who display an OTHER pattern to the corresponding propositions. Distinguishing these is interesting because those children who were IND in the proposition task can be expected to answer correctly on the (putatively easier) question task; and if, as argued earlier, the OTHER children are transitional subjects who have a fragile understanding of indeterminacy, then the single object questions may improve performance for those children if it is indeed the case that it is a cognitively less demanding task.

Figure 4 presents the relevant data. Subjects are divided into those who exhibited a deterministic (DET) pattern of responses in the relevant twin proposition task (i.e., the modal proposition task in the case of modal questions and the copula proposition task for copula questions), those who exhibited an IND pattern, and those who exhibited an OTHER pattern in that task.

Clearly, for the nondeterministic children, the questions remain considerably easier. The crucial comparison is that concerning OTHER subjects, whose performance is much higher for questions than for propositions: 83% versus 38% correct overall ($z = 2.76$, $p < .01$); and similar values for copula and modal

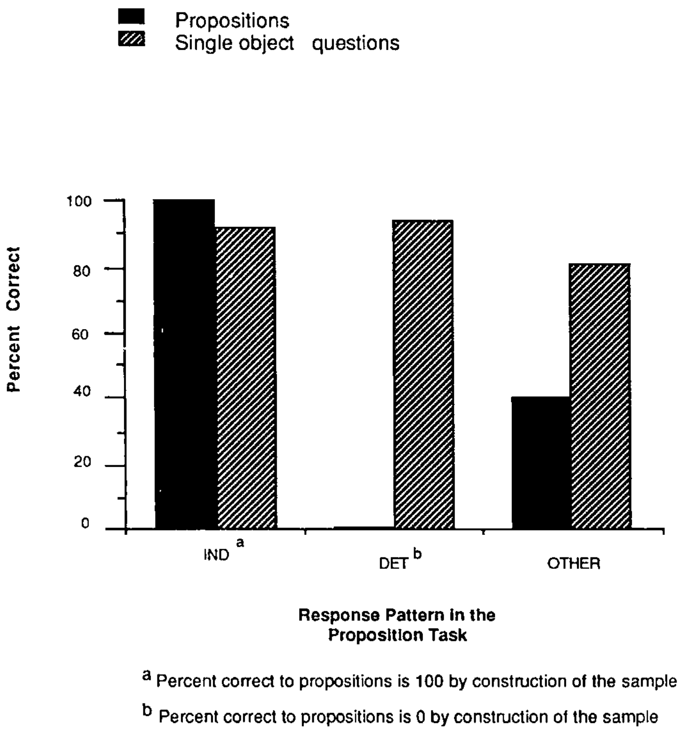

Figure 4. Experiment 2: Percent correct (% correct responses to copulas; % correct pairs of responses to modals) to indeterminate questions and propositions, for subjects who exhibit, respectively, an IND, DET, and OTHER pattern of response in the proposition task (see Table 1 for definition of IND, DET, and OTHER)

sentences separately. (For the IND and the DET children, the comparison is artifactually constrained, since their performance to propositions is, respectively, 100% correct and 0% correct, by construction of the sample.) Another observation is that all three sets of children (DET, IND, OTHER) exhibit very similar performances to single object questions (92%, 87%, and 83% correct, respectively), despite their considerable differences regarding propositions. Both observations support the conclusion that single object questions are genuinely easier.

The second, crucial analysis concerns order effects between tasks. If success on single object questions stems from a deterministic, "indeterminacy of sampling" process, then there is no reason to expect this task to facilitate performance to the quantified inferences when these are presented subsequently. If, however, the single object questions do lead to insight into the logical indeterminacy of the situation, then performance on the quantified inferences should improve when they follow the question tasks. Examination of the first pair of tasks presented to each child reveals that this is indeed the case: The percent correct (to indeterminate inferences) in the proposition task is 25 when that task is first of the pair, and 50 when it occurs after the question task ($z = 1.67$, $p < .05$). This is not simply a general negative primacy effect: The corresponding percentages for the question task are 85 and 80, respectively. Thus, this analysis strongly suggests that the single object questions afford genuine insight into the indeterminacy of the referent situation.

Discussion

These results reveal that the questions bearing on single invisible objects are easier than the quantified propositions in this experiment. They furthermore reveal that this phenomenon reflects a genuine apprehension of the logical indeterminacy of the referent situation (and thus is not trivially due to the possibility that correct responses to those questions might stem from a deterministic representation and the uncertainty of sampling). The key results on this point are that reasoning with single object questions improved performance on the subsequent proposition task, as it should if a genuine "indeterminate" understanding was involved but not if a vicariously correct response was involved, and that even for those specific children who were assessed as having a nondeterministic representation of the premise, the single object questions were considerably easier than the corresponding quantified propositions.

Most crucially, those questions were easier for children with an OTHER pattern of responses, which, based upon previous results (see discussion of Experiment 1), can be taken to be transitional patterns reflecting a weak understanding of indeterminacy. Thus, single object questions appear to enable those children to use their fragile representation of indeterminacy profitably. More will be said on this shortly.

Before elaborating on this point, a word is in order about the results of IND subjects (i.e., of subjects with an IND pattern of responses in the proposition task). These subjects answered single object questions without error (as they did, by definition, for quantified propositions). While this is not surprising, the equivalence of the propositions and questions for these subjects is not trivial, since the percent correct to questions is free to vary while the "proposition" value is constrained to be 100 by construction of the sample. Thus, this result is consistent with the previous conclusions regarding the relative ease of single object questions.

Quantified inferences and single object questions are likely to entail different deductive processes, placing different demands on the logical executive function. For quantified inferences, it appears that, as argued in Falmagne (1975b) and summarized in the introduction to this experiment, the initial encoding of the premise *In this box, there are only big circles* is indeed a schematic representation consisting of a big colorless circle, but that a more fully specified representation including a tentative set of colored circles is brought up selectively in the process of answering indeterminate inferences (e.g., *In this box, there is a red circle*). Based on the results, this representation could, equivalently, either be imagistic or consist of a feature list. In contrast, in the case of single object questions, it seems likely that this unfolding of the initial, schematized representation into a different representation is not needed since the question about an invisible object is congruent with the form of the existing representation; a simple match between the initial representation and the current question suffices.

Aside from other differences in processing demands, the absence of that additional unfolding and of the subsequent combinatorial analysis may explain the greater robustness of indeterminate reasoning with single object questions. As discussed previously, logical knowledge is seen here as having both a representational and an executive function: It is involved both in generating the initial representation and in subsequently monitoring the execution of the entire inferential process. Thus a fragile understanding may be sufficient to sustain the conception and execution of a simple verification program, but insufficiently articulated or insufficiently robust to sustain a more elaborate program, even when the initial representation of the premise is the same.

A more specific tentative account consistent with these notions is as follows. The initial schematized representation held by children who have some understanding of indeterminacy (leaving aside those children who are explicitly deterministic), would contain the correct size and shape information (e.g., a big circle), but for different kinds of subjects the information about the color of objects in the box would be tagged differently. For some children, the absence of such information would be *explicit* in the initial, schematized representation, thus reflecting an understanding of the logical indeterminacy of the situation in that respect. When this initial representation is unfolded to answer quantified inferences, the child's explicit understanding would sustain a correct tagging of the various colors as tentative, and a correct combinatorial plan for imagining the content of the box, thus leading to essentially correct performance on those inferences. This process would be characteristic of the IND children (barring some random noise between the underlying process and the actual response). In contrast, an intermediate level of understanding, and that of most interest here, would be one in which the initial representation contains the correct size and shape information (a big circle), but has *default values* for the two other dimensions (color and number), thus reflecting a weak, inexplicit understanding of indeterminacy. This would be characteristic of the OTHER and perhaps of some DET children. Those children answer single object questions correctly because the logical executive simply generates a straightforward comparison between the "default" representation and the probe. However, when required to unfold that representation in the case of quantified inferences, those children would unfold it incorrectly because their understanding is weak. The default tags cannot guide a coherent plan for generating an explicit array of tentative circles and an appropriate combinatorial analysis; hence, the OTHER (and occasionally DET) patterns of responses for those children. So, in this case, even though the relevant logical understanding is present, and sufficient to provide insight into the single object questions, it is too fragile and inarticulated to sustain the complex verification program required for quantified inferences.

Two features of this account deserve mention. First, again, it should be noted that this analysis differs from a competence–performance conceptualization. Rather, on the present conception, the execution of the entire process is monitored by the logical executive function. Second, the account involves a functional characterization of understanding in terms of its fragility or robustness, in addition to the usual computational characterization. For instance, although the default tags would be computationally sufficient to derive an array of circles of tentative colors, it is proposed that, functionally speaking, they reflect too fragile an understanding to do so.

Thus, in the foregoing account, the difficulty of quantified indeterminate inferences, relative to single object questions, results from the greater demands that they place on the logical executive function. In this specific case, the additional demands were characterized as involving an additional unfolding step and a quasi-combinatorial analysis; eliminating those demands enabled the initial representation to yield correct deductions. More generally, however, these results suggest that part of the difficulty of indeterminate inferences is attributable to the logical executive rather than to the logical representational function. This point will be elaborated in the final discussion.

EXPERIMENT 3

The conclusions from Experiment 2 are based on two sets of analyses: the sequential effects between question and proposition tasks, and the behavior of children assumed to use a nondeterministic initial representation of the premise.

The latter analysis relies on the assumption that children who used an initial indeterminate representation of the premise in the twin proposition task did so in the relevant question task as well. Indirect evidence on this point is provided by the data of Experiment 1, indicating that there was a high level of between-task consistency: Within two tasks using the same lexical formulation (modal or non-modal), there was a .70 probability of a second IND pattern given that the pattern on the first task was IND, or of a second DET pattern given that the first pattern was DET. (For obvious reasons, only those two extreme patterns are included in this particular analysis, since OTHER patterns are not required to be consistent across tasks, given their interpretation.) Nevertheless, while it is unlikely that the results of Experiment 2 can be entirely accounted for by a shift in initial mode of representation between the two tasks, the result concerning single object questions is interesting enough to warrant replication under more tightly controlled conditions. This was the purpose of Experiment 3.

This experiment addressed the same question as Experiment 2, but was designed to maximize the likelihood that responses to the single object questions and responses to the quantified propositions would be based on the same initial representation of the premise. This was done by presenting both kinds of inferences within a single task. Only non-modal (copula) propositions and questions were used in this experiment; modal inferences were not included in order to permit within-subject replications of the task without unduly increasing the length of the session.

Methods

Twenty-two subjects (11 second graders and 11 third graders) were administered two tasks, formally identical to each other but each with a different premise. The reference set and the general procedure were identical to those of Experiments 1 and 2. However, this time quantified propositions and single object questions were administered within the same task, with—obviously—the same premise. Only non-modal, copula items were used. Each task included six propositions and six single object questions (each with two true, two false, and two indeterminates).

Results

Again, as in Experiment 2, data from the two age groups were pooled for purposes of analysis. These two subject samples were included for comparability with the sample of Experiment 1 only and were not a variable of interest in this experiment.

As a first result of interest, the percent correct responses to indeterminate propositions and indeterminate questions was 53 and 90, respectively ($z = 2.76$, $p < .01$). These values are comparable to the corresponding values obtained in Experiment 2 for copula propositions and questions (50 and 90, respectively). As in Experiment 2, performance on determinate true and false items was virtually errorless.

However, as argued previously, the more informative analysis is to consider separately those children who exhibited a deterministic pattern of responses to the corresponding propositions and those who exhibited a nondeterministic pattern, as was done in Figure 4. In the present experiment, the propositions and questions of interest are part of the same task, in contrast to Experiment 2.

Figure 5 presents the relevant data. Clearly, both those who exhibit a DET pattern to propositions within a task and those who exhibit an IND pattern to propositions perform almost errorlessly on the single object questions. Few children exhibit OTHER patterns (there are only six instances of this kind, produced by five children); for those, performance on the questions is markedly higher than performance on the propositions (67% vs. 42% correct, respectively). This difference, based on a small number of observations (12 per cell)

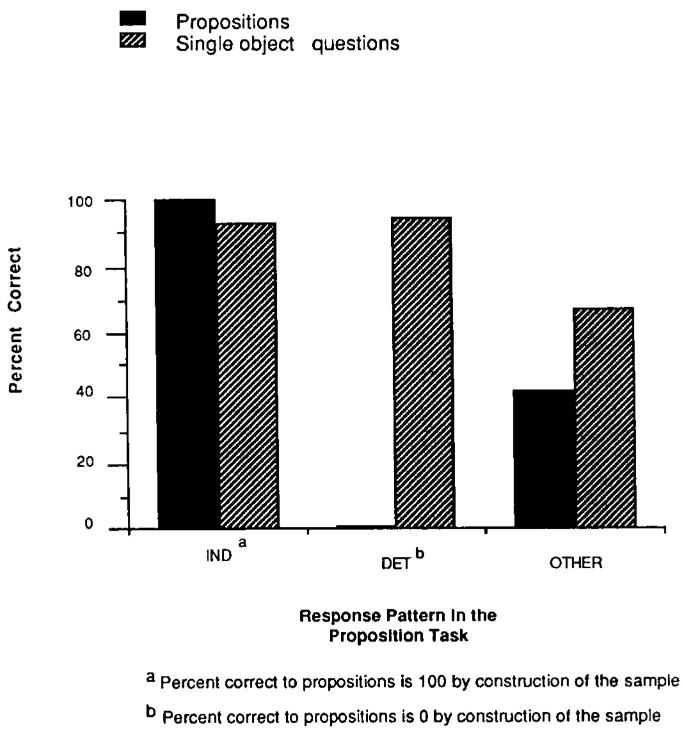

Figure 5. Experiment 3: Percent correct (% correct responses to copulas; % correct pairs of responses to modals) to indeterminate questions and propositions for subjects who exhibit, respectively, an IND, a DET, and an OTHER pattern of responses in the proposition task (see Table 1 for definition of IND, DET, and OTHER)

Sternberg, R. J. (1979). Developmental patterns in the encoding and combination of logical connectives. *Journal of Experimental Child Psychology, 28*, 469–498.

Taplin, J. E., Staudenmayer, H. & Taddonio, J. L. (1974). Developmental changes in conditional reasoning: Linguistic or logical? *Journal of Experimental Child Psychology, 17*, 360–373.

Wason, P. C., & Johnson-Laird, P. N. (1972). *The psychology of reasoning.* Cambridge: Harvard University Press.

Wollman, W. T., Eylon, B., & Lawson, A. E. (1979). Acceptance of lack of closure: Is it an index of advanced reasoning? *Child Development, 50*, 656–665.

misses significance, however ($z = 1.23$, $p = .11$). This result qualitatively replicates the corresponding result in Experiment 2 (83% vs. 38% correct for questions and propositions, respectively, 36 observations for each, $z = 2.76$, $p < .01$) as can be verified from Figure 4.

Discussion

Again, as was the case in Experiment 2, single object questions are indeed easier than quantified inferences, for all categories of children. Most important, these questions are easier for OTHER subjects, that is, those who, based on previous results, can be interpreted as having a fragile understanding of indeterminacy. The advantage of single object questions was considerable for those children in Experiment 2 and qualitatively replicated in the present experiment under more tightly controlled conditions, with a fortuitously smaller data sample (only six individual tasks revealed OTHER patterns).

Thus, the results of both experiments converge to indicate that when the required deductive procedure is modified in the relevant manner (see discussion of Experiment 2) while leaving unchanged the logical form of the inference, judgments of indeterminacy become easier, suggesting that the previous difficulties were partly linked to the burden placed on the logical executive function.

CONCLUSIONS

Our central questions concerned the factors involved in judgments of indeterminacy, particularly the contribution of logical form per se as opposed to other linguistic factors, and the contribution of executive factors, as opposed to representational factors, to the difficulty of those judgments.

Three results stand out in regard to those questions. The difficulty of indeterminate inferences remains when inferences phrased in copula, non-modal language are rephrased in modal language. It remains when inferences phrased in proposition form are rephrased as questions. However, when the judgments concern single hypothetical objects rather than the composition of a hypothetical set, judgments of indeterminacy become considerably easier. These results will be discussed in turn.

Some previous accounts regarding the difficulty of judgments of indeterminacy in deductive tasks can be discarded based upon these results. The difficulty is clearly not linked to the use of the response *can't tell* (as Braine & Rumain, 1983, among others, have suggested), since it holds when judgments of indeterminacy are given through pairs of *true* and *false* responses, as they are in the modal tasks. Similarly, the difficulty is not related to the specific task demands of truth value judgments, since it holds with inferences phrased as questions.

Another possibility is eliminated as well, and the results regarding modals and those regarding questions converge in a general way in that respect. Both the modal formulation and the question form "lexicalize" the inference, loosely speaking, making it work in and on stable cognitive units. In the modal formulation, the logical form of the inference is given by the semantics of the modal terms *can* and *have to* rather than by sentence structure; here, lexicalization applies to the embodiment of logical form. In the question form, the inference–response pair is simplified linguistically in a qualitatively similar way, in that it only requires discourse-level comprehension processes as opposed to metalinguistic judgments about entities at the discourse level. Thus here, analogically speaking, there is a trend towards lexicalization of the response component of the process. The motivation for introducing both these variables was similar: to examine whether lexicalization would reduce the difficulty of judgments of indeterminacy. It is interesting that neither variable was effective in that respect although both were cognitively relevant in other ways.

Thus, these results indicate that the difficulty genuinely involves the logical form of the inferences, since simplifying the inferences linguistically was ineffective. The aim of this article was to delineate the nature of this difficulty. The dual conception of logical knowledge discussed previously maintains that logical knowledge is involved in deduction both in a representational capacity, in determining the initial representation, and in an executive capacity, in controlling and monitoring the subsequent deductive procedures (Falmagne, 1985). Within this view, there are, a priori, two potential (nonexclusive) accounts about the locus of the difficulty of indeterminate inferences.

One account is representational: There would be general difficulties in forming semantic representations that include indeterminacy. On this account, children's poor performance in our task (and in the literature) would result from an erroneous initial encoding of the premise, due to the unavailability or limited availability of the appropriate logical form in children's semantic network. Although this account may capture part of the phenomenon, the present results show that it is insufficient for explaining the phenomenon in its entirety.

A second account of the children's difficulties centers on logical executive factors. On this account, (a) the process involved in establishing the indeterminacy of a statement is intrinsically more complex than the process involved in judgments of truth and falsity, and (b) children's initial representation of indeterminacy may be too fragile sometimes to sustain the design and/or execution of those procedures.

That the introduction of single object questions considerably facilitated deduction strongly points to the involvement of such executive factors. That this variable was important for those children displaying a fragile understanding of indeterminacy (OTHER subjects) further reinforces this interpretation.

There have been a number of proposals suggesting, on various grounds, that judgments of indeterminacy involve mental processes more complex than those yielding judgments of truth and falsity (e.g., Braine, 1978; Falmagne, 1975b; Johnson-Laird, 1983). This notion is also supported, in the experiments reported here, by the fact that those children who showed evidence of using an indeterminate representation (children with IND or OTHER patterns of responses) had longer latencies in responding to the indeterminate inferences than in responding to the true and false inferences.

Yet, despite its theoretical importance, deductive complexity had not been manipulated directly so far. Previous discussions of this issue have been speculative and, furthermore, have focused on comparing indeterminate with determinate inferences in that respect, thereby confounding deductive complexity and response category. The single object questions in Experiments 2 and 3, by simplifying the deductive process for indeterminate inferences in a theoretically meaningful way, allow an examination of that factor unconfounded by the logical form of the inference. Therefore, the present results highlight the contribution of deductive complexity per se (as opposed to response factors) to the well-known difficulties of indeterminate reasoning.

According to the specific account offered in the discussion of Experiment 2 for our tasks, the introduction of single object questions made the comparison process simpler and more straightforward by making it possible to rely on the initial, schematic representation in order to generate a response, thereby bypassing the hazardous unfolding of that representation into a more explicit representation and a complex verification procedure. This was particularly important for transitional (OTHER) subjects, who presumably encoded the initial indeterminate referents in an inexplicit way, and whose default tags for indeterminacy were too weak to guide the execution of a complex process.

More generally, within the dual conception of logical functioning discussed in this article, one difficulty of indeterminacy would be in generating a correct comparison process between the functional representation of the premise and the probe, and in monitoring the execution of that process. That phenomenon would be particularly crucial when the initial logical understanding is weak, due to the demands placed on the logical executive function; in that case, the deductive procedures are insufficiently directed by children's fragile understanding of the logic of the problem, even when their initial representation of the premise is correct.

Note that this account, while stressing the role of the executive logical function, indirectly involves a representational aspect as well: Clearly, executive weakness stems from a weak initial representation. This point was illustrated here (see discussion of Experiment 2) by the two different ways in which, putatively, indeterminacy was represented in solidly indeterminate and in transitional subjects, that is, as an explicit absence of some information or as default tags, respectively. Note also that, as remarked on earlier, this dual characterization of logical functioning is not a competence–performance construal: The deductive process is a procedural embodiment of the subject's logical knowledge, and its organization and its execution are monitored by that knowledge.

Within this dual view, the development of logical functions can be characterized as involving two interrelated aspects. Representationally, development involves a conceptual restructuring, an expansion and reorganization of the child's logico-semantic network in terms of the repertoire of logical forms it includes, and an expansion in the range of surface expressions in which a given logical form will be recognized (see Falmagne, 1980, 1985, for a discussion of these issues). Furthermore, development involves a strengthening of the executive control processes underlying deduction for a given logical form, from a level of fragile competence sufficient to monitor simple processes only, to a level at which the initial representation is robust enough to generate and execute a complex deductive program.

As pointed out in the introduction to this article, the difficulty in recognition of indeterminacy has been discussed by accounts at different "grains" of analysis. Piagetian accounts of that difficulty in children are based on a global restructuring of the system of cognitive operations in the course of cognitive development. The present analysis is neither constrained by, nor incompatible with, such an account. At the finer grain of analysis adopted here, the interesting phenomenon is that, within the general trend regarding the diffituity of indeterminate conclusions, executive factors appear to carry much of the burden of that difficulty, at least in our tasks. As remarked earlier in this section, previous studies either have not attempted to vary processing complexity within indeterminate inferences, or have not been able to do so given the particular deductive situation at hand. The present results raise the question, therefore, of whether executive factors may be largely responsible for some cognitive behaviors previously attributed to conceptual/representational failures.

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