The Primacy of Thinking About Possibilities in the Development of Reasoning

Caroline Gauffroy and Pierre Barrouillet
Université de Genève

One of the main tenets of the mental model theory is that when individuals reason, they think about possibilities. According to this theory, reasoning on what is possible from the truth of a sentence would be psychologically basic, whereas reasoning the other way round, on the truth or falsity of a sentence from a given state of affairs, would require some meta-ability. The present study tested the developmental corollary of this theory, which is that reasoning about possibilities should develop first, whereas the development of reasoning about truth-value should be delayed. For this purpose, 3rd, 6th, and 9th graders as well as adults were presented with tasks requiring them to evaluate either the possibilities compatible with conditional sentences or the truth-value of these sentences from these same possibilities. The results revealed 2 phenomena. First, the same developmental trend was observed in both tasks with 3 successive interpretational levels: conjunctive, biconditional, and then conditional. Second, there was a developmental lag between the 2 forms of reasoning—with developmental transitions from one level to the next occurring about 3 years later when reasoning about truth-value. The implications of these results for theories of cognitive development and of reasoning are discussed.

Keywords: conditional reasoning, mental models, cognitive development, metacognition

What the basic processes involved in human reasoning are and how these processes develop with age have been among the most challenging questions of psychology. The answer proposed by Piaget (Inhelder & Piaget, 1958) was that children construct logical structures of thought with increasing power and abstractness by differentiating and coordinating schemes into reversible operations. Other authors have assumed that human beings are equipped with a mental logic made of syntactic rules of reasoning, some being innate and others acquired (Braine, 1990). In the last decades, Johnson-Laird developed his influential mental model theory, which assumes that people interpret sentences and reason from them without any recourse to logical structures or rules but simply by constructing and manipulating mental models of the possibilities that can occur given the truth of the premises (Johnson-Laird, 1983, 2006; Johnson-Laird & Byrne, 1991). Thus, the main assumption of the mental model theory is that when individuals reason, they think about possibilities (Johnson-Laird, 2006). Though this theory has inspired several developmental models (Gauffroy & Barrouillet, 2009; Markovits, 1993; Markovits & Barrouillet, 2002), it leads to a developmental prediction that, to the best of our knowledge, has never been tested. If representing possibilities is the fundamental process on which reasoning always relies, then this process should be genetically the first. Thus, reasoning about possibilities should develop earlier and, at least during the developmental period, should be easier than other forms of reasoning. The aim of the studies presented in this article was to test this prediction.

For this purpose, we chose to investigate conditional reasoning. Understanding conditionals is important for the development of essential human abilities such as scientific reasoning and hypothesis testing (Kuhn, Amsel, & O’Loughlin, 1988), causal learning (Kushnir & Gopnik, 2007), or understanding social rules (Harris & Nunez, 1996; Light, Blaye, Gilly, & Girotto, 1989). Moreover, the if . . . then conditional connective presents interesting peculiarities that make it especially suited to contrast reasoning about possibilities with other forms of reasoning. Consider the following sentence about the content of boxes in a grocery store:

If the box is red, then it contains cherries,

and think about what is possible. Assuming that this sentence is true, is it possible to have a red box containing cherries? And a green box containing apples? For adults, the answer to both questions is the same, and this answer is “yes.” Now, imagine that the truth-value of the sentence is uncertain and put under scrutiny. Would the two color boxes provide the same information about the truth or falsity of the sentence? As will be shown, many adolescents and adults give a negative answer to the latter question, considering that the red box with cherries makes the conditional true, whereas the green box with apples leaves its truth-value indeterminate. Thus, when considering conditionals, reasoning about what the possible states of affairs are given the truth of a sentence seems to differ from reasoning the other way round, about the truth or falsity of this sentence from given states of affairs. In the following studies, we contrast the two kinds of reasoning in

This article was published Online First March 28, 2011.
Correspondence concerning this article should be addressed to Pierre Barrouillet or Caroline Gauffroy, Université de Genève, Faculté de Psychologie et de Sciences de l’Education, 40, bd du pont d’Arve, 1205 Genève, Switzerland. E-mail: pierre.barrouillet@unige.ch or caroline.gauffroy@unige.ch
children, adolescents, and adults in order to test the hypothesis that reasoning about possibilities develops first.

The Mental Model Theory of Conditionals

The mental model theory stipulates that when interpreting a conditional statement of the form If p then q such as “If the box is red, then it contains cherries,” reasoners construct mental models of the states of affairs that the sentence describes (Johnson-Laird & Byrne, 1991, 2002). However, because constructing and manipulating more than one model at a time imposes a load on working memory, reasoners would only explicitly represent the possibility in which the antecedent is satisfied (i.e., red box) and leave implicit the other possibilities (Johnson-Laird & Byrne, 1991). So, in a first step, individuals would construct an initial representation of the following form:

\[ p \quad \ldots \]

in which the first line represents explicitly the possibility in which the box is red and contains cherries. The three dots denote a model with no explicit content that rules out the conjunctive interpretation by implicitly representing the possibilities for which the if clause is false. If needed, implicit information can be made explicit by a time-consuming and demanding fleshing out process resulting in the construction of two additional models: \( \neg p \land q \) and \( \neg p \lor \neg q \) (in our example, the possibility in which the box is not red and does not contain cherries and the possibility in which the box is not red but contains cherries). The fleshing out leads to the following complete three-model representation, where \( \neg \) denotes a negation tag:

\[ p \quad q \quad \neg p \quad \neg q \quad \neg p \land q. \]

It is worth noting that these models do not correspond to a truth table, because each entry in a truth table represents the truth or falsity of an assertion, whereas these models represent possibilities. Consequently, according to the mental model theory, possibilities are psychologically basic, whereas discourse about the truth or falsity of propositions is a meta-ability of a higher level than mere descriptions of possibilities (Johnson-Laird & Byrne, 2002).

This distinction between reasoning about possibilities and reasoning about truth-values would have at least two consequences. The first is that representing possibilities should be a primary mental process whose development precedes other forms of reasoning. The second consequence is that, though being developmentally delayed, other forms of reasoning such as reasoning about truth-values should follow the same developmental trend. This is because all forms of reasoning are underpinned, at least in their first steps, by the representation of possibilities. As far as we know, these predictions have never been tested. However, previous studies on both kinds of reasoning have provided promising results that partially confirm some of these assumptions.

Reasoning About Possibilities and Reasoning About Truth-Values

The development of reasoning about possibilities related to conditional statements has been widely documented (Barrouillet, Grosset, & Lecas, 2000; Barrouillet & Lecas, 1998, 1999, 2002; Lecas & Barrouillet, 1999). A variety of tasks that involved the identification of cases that are impossible or the construction of all possible cases given the truth of the conditional revealed three successive developmental levels. First, young children exhibit a conjunctive interpretation underpinned by the construction of a single model corresponding to the explicit model within the initial representation of the conditional. At this level, they fail to represent other possibilities and consider the sole \( p \land q \) case as compatible with the conditional. Adolescents reach a biconditional interpretation underpinned by the construction of two models and consider \( p \land q \) and \( \neg p \land \neg q \) cases as compatible with If \( p \) then \( q \) sentences, whereas older adolescents and adults construct the complete three-model representation corresponding to a conditional interpretation (see Table 1). As a consequence, they reject only the \( p \land \neg q \) cases as incompatible with the conditional.

Interestingly, this developmental trend has also been observed in tasks that do not require a person to reason about what is possible given the truth of a conditional but instead to reason about the truth or falsity of this conditional given some state of affairs. In recent studies, we used for this purpose a truth-value task in which children, adolescents, and adults were presented with a conditional statement (Barrouillet, Gauffroy, & Lecas, 2008; Gauffroy & Barrouillet, 2009). They were then asked to judge for each of the four logical cases whether it made the conditional true or false or whether it left its truth-value indeterminate. This third alternative was introduced because several studies with adults revealed that

<table>
<thead>
<tr>
<th>Logical cases</th>
<th>Conjunctive Possibilities</th>
<th>Conjunctive Truth-value</th>
<th>Biconditional Possibilities</th>
<th>Biconditional Truth-value</th>
<th>Conditional Possibilities</th>
<th>Conditional Truth-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>( p \land q )</td>
<td>Compatible</td>
<td>True</td>
<td>Compatible</td>
<td>True</td>
<td>Compatible</td>
<td>True</td>
</tr>
<tr>
<td>( \neg p \land q )</td>
<td>Incompatible</td>
<td>False</td>
<td>Incompatible</td>
<td>False</td>
<td>Incompatible</td>
<td>False</td>
</tr>
<tr>
<td>( \neg p \land \neg q )</td>
<td>Incompatible</td>
<td>False</td>
<td>Incompatible</td>
<td>False</td>
<td>Incompatible</td>
<td>False</td>
</tr>
<tr>
<td>( p \land \neg q )</td>
<td>Incompatible</td>
<td>False</td>
<td>Incompatible</td>
<td>False</td>
<td>Incompatible</td>
<td>False</td>
</tr>
</tbody>
</table>
they usually judge indeterminate the truth-value of the conditional for false-antecedent cases (i.e., $\neg p$ cases), producing the so-called defective truth table, in which the conditional is deemed true for the $p \ q$ case and false for the $p \neg q$ case, but its truth-value is left indeterminate for the $\neg p \neg q$ and $\neg p \ q$ cases. We have recently proposed to account for this defective table by assuming that the models constructed have different epistemic statuses depending on the processes that underpin their construction (Barrouillet et al., 2008). Because the initial model spontaneously comes to mind through tacit and unconscious processes, it constitutes the core meaning of the sentence, and people consider the cases that match this model (i.e., $p \ q$) as making the conditional true when they occur. By contrast, the fleshing out process leading to the construction of additional models is optional because it is demanding and time consuming. As a consequence, the cases matching these additional models (i.e., $\neg p \neg q$ and $\neg p \ q$ cases) are compatible with the conditional, but they are not considered as pertaining to its core meaning and as making it true. Thus, reasoners often consider that these cases leave indeterminate the truth-value of the conditional. Finally, the cases that are not represented in any model make the conditional false when they occur.

Our developmental studies using the truth-value task revealed the same developmental levels already observed in reasoning about possibilities (Barrouillet et al., 2008; Gauffroy & Barrouillet, 2009). Young children adopt a conjunctive interpretation and consider that the $p \ q$ cases make the conditional true whereas the three other cases make it false. Adolescents who are able to flesh out the initial model with the additional model $\neg p \neg q$ consider the $p \ q$ cases as making the conditional true, the $\neg p \neg q$ cases as leaving its truth-value indeterminate, and the two other cases as making it false. This response pattern, known as defective biconditional, reflects the same interpretational level as the biconditional developmental level previously described. Finally, older adolescents and adults exhibit the defective truth table as described earlier in which the conditional is deemed true for $p \ q$, indeterminate for $\neg p \neg q$ and $\neg p \ q$, and false for the sole $p \neg q$ case. We assumed that this pattern results from a complete three-model representation, thus reflecting the conditional level of development (see Table 1).

Comparing the Two Kinds of Reasoning: 
The Present Study

The most important fact arising from these studies is that the two kinds of reasoning present the same succession of developmental levels from a conjunctive, a biconditional, and then a conditional interpretation. However, this does not mean that they develop in synchrony with each other. If reasoning about possibilities involves basic processes corresponding to the natural functioning of the mind, then this type of reasoning should be easier and develop earlier than does reasoning about truth-values. The shift from a conjunctive to a biconditional interpretation, which usually occurs in sixth graders when reasoning about possibilities (Barrouillet & Lecas, 1998), should occur later on in reasoning about truth-values. This should also be observed for the shift from the biconditional to the conditional interpretation usually achieved in ninth graders when reasoning about possibilities.

To test these predictions, we proposed two tasks to third, sixth, and ninth graders and adults. In the first task, participants had to judge whether each of the four logical cases was compatible or incompatible with a conditional statement. In the second task, they had to judge, for each of the four logical cases, the truth-value of the conditional. In both tasks, participants were presented with drawings of a box containing two colored objects (a circle on the left and a star on the right) along with the conditional sentence “If the circle is (red), then the star is (black).” We manipulated the correspondence between the colors of the circle and the star in the box and those stipulated in the conditional statement to form four trials for each of the four logical cases (i.e., $p \ q$, $p \neg q$, $\neg p \ q$, and $\neg p \neg q$). Both tasks were introduced by a scenario involving pupils in a classroom and their teacher. In the possibilities task, the conditional was presented as an instruction that pupils received to fill boxes with a circle and a star. Participants were asked to study the contents of each box and to say whether the child respected the instruction and whether the child was right or wrong when filling the box. In the truth-value evaluation task, a teacher filled five boxes by complying with a rule and asked pupils to discover this rule by studying the content of four out of these five boxes. The same trials as in the possibilities task were presented to the participants, to whom the conditional rule was presented as the putative rule discovered by a pupil, and the circle and the star as the contents of the fifth box not yet studied. Participants were asked to judge whether the contents of the box made the putative rule true or false or whether it left its truth-value indeterminate (i.e., “one cannot know” whether the discovered rule is true or false). It should be noted that the use of a traditional truth-value evaluation task with three possible responses (i.e., “true,” “false,” “one cannot know”) introduced a difference between the two tasks concerning the number of proposed alternatives. In order to control for a possible confound, we ran a control experiment involving the same age groups and the same tasks, except that the truth-value evaluation task proposed only two possible responses (i.e., “true” and “false”). Because both experiments led to similar results, their results will not be reported separately.

We made two main predictions. First, we expected that both tasks would have the same developmental trend (i.e., conjunctive, biconditional, and then conditional responses), with the expected responses for each logical case corresponding to those described in Table 1. However, our main prediction was that this development should be delayed for the truth-value task. It can be observed in Table 1 that, through the successive developmental levels, children’s and adolescents’ responses conform progressively to those characterizing the conditional pattern predominant in adults. Thus, 1 Schroyens (2010) has recently cogently argued that giving the “true” option is misleading because a single case can never prove a general rule to be true. In the same way, adding a “corroborate” option (i.e., the case makes the rule more plausible but is neither true nor false) significantly reduces the rate of “irrelevant” responses. Though these analyses and facts improve the understanding of the way adults interpret If $p$ then $q$ conditions, we nevertheless chose to use the more traditional three-option task with “true,” “false,” and “one cannot know” options for the truth-value task. Indeed, it is doubtful that children and adolescents are aware of the induction problem that makes it impossible to prove a general rule to be true from a single case. Moreover, our hypotheses mainly concern the rates of “false” responses compared with “incompatible” responses in the possibilities task, options that are not misleading: A single case can prove a general rule to be false (e.g., $p \neg q$ for If $p$ then $q$).
the developmental level of a given child or adolescent can be assessed by evaluating how many responses he or she gives that correspond to the modal response observed in adulthood. For the possibilities evaluation task, this modal response corresponds to “compatible” for the $p \land q$, $\neg p \land \neg q$, and $p \land q$ cases and “incompatible” for the $p \land \neg q$ case. For the truth-value evaluation task, it corresponds to “true,” “indeterminate,” “indeterminate,” and “false,” respectively, for the three-response version and to “true,” “true,” and “false,” respectively, when only two alternative responses are proposed. We call these responses conditional responses, according to the interpretation that underpins the modal response pattern observed in adults.

Accordingly, we predicted that the rate of conditional responses should steadily increase with age for both tasks but that this rate should be lower for the truth-value task compared with the possibilities task. We can formulate even more precise predictions concerning the discrepancies between the two kinds of reasoning. Previous studies have shown that the developmental shift leading from the conjunctive to the biconditional interpretation usually occurs around sixth grade for reasoning about possibilities (Barrouillet et al., 2000; Barrouillet & Lecas, 1998, 2002). The $\neg p \land \neg q$ case that is considered “incompatible” in the conjunctive interpretation is considered “compatible” within the biconditional interpretation. So, the hypothesis of a developmental lag predicts that, in sixth graders, $\neg p \land \neg q$ cases will elicit a higher rate of conditional responses in the possibilities task (i.e., “compatible” responses) than in the truth-value task, in which the “indeterminate” responses (or the “true” response in the control experiment) should be rarer. Indeed, in the truth-value task, $\neg p \land \neg q$ cases should still elicit a high rate of “false” responses that are characteristic of the conjunctive interpretation. The same phenomenon should occur for the $\neg p$ case but later in development. The aforementioned studies on the possibilities task revealed that the conditional interpretation in which both the $\neg p \land \neg q$ and $p \land q$ cases are compatible with the conditional occurs at the end of adolescence. The hypothesis of a delayed development of reasoning about truth-value would thus predict the existence of a developmental level, probably around ninth grade, in which the $p \land q$ cases should be considered as compatible with the conditional while still falsifying it when reasoning about its truth-value. This difference between the two tasks concerning the $\neg p$ cases would not appear in younger participants, who are not able to reach the conditional level, even with the easiest task. If the idea that adults have sufficient capacities to overcome the inherent difficulty to reason about truth-values and access the conditional level in both forms of reasoning is retained, the difference should disappear.

**Method**

**Participants**

Forty-one third graders (31 female; mean age = 8.5 years, SD = 0.19), 41 sixth graders (29 female; mean age = 11.7 years, SD = 0.26), 39 ninth graders (24 female; mean age = 15.5 years, SD = 0.31) from primary schools and high schools in the urban area of Geneva and 51 students from the University of Geneva (30 female; mean age = 23.5 years, SD = 1.92) participated. Third, sixth, and ninth graders volunteered with parental informed consent, and university students participated for partial fulfillment of a course requirement. About half of the participants in each level performed the possibilities task (22 third, 20 sixth, and 19 ninth graders and 26 university students), and the other half completed the truth-value task. Four different groups of third, sixth, and ninth graders and adults were involved in the control experiment.

**Material and Procedure**

In both experiments, the two tasks were completed by groups of about 20 participants. For both types of tasks, a conditional statement, displayed at the top of a screen by a video projector, described the contents of a box in which there were always a colored circle on the left and a colored star on the right (e.g., “If the circle is red, then the star is yellow”). The experimenter read the conditional statement aloud and asked the participants to pay attention to the statement. After 7 s, the box (a rectangle) appeared in the middle of the screen. After a delay of 1 s, the circle appeared, followed by the star after 2 s; the experimenter said aloud the color of these two items. Finally, three boxes corresponding to the response possibilities (i.e., “true,” “one cannot know,” and “false”) for the truth-value task and “compatible” and “incompatible” for the possibilities task) were displayed at the bottom of the screen. The same boxes corresponding to the response possibilities were reported on the participants’ response sheet, and participants gave their responses by marking the appropriate box. For the truth-value task of the control experiment, only two boxes (“true” and “false”) appeared on the screen, and they were also reported on response sheets.

Sixteen different pairs of colors were used. The correspondence between the color of the circle and the star in the box and those stipulated in the conditional statement was manipulated to form four trials for each of the four logical cases (i.e., $p \land q$, $\neg p \land q$, $p \land \neg q$, $\neg p \land \neg q$).

---

2 The participants in the control experiment were 46 third graders (27 female; mean age = 8.8 years, SD = 0.42), 46 sixth graders (25 female; mean age = 11.9 years, SD = 0.16), 46 ninth graders (30 female; mean age = 15.4 years, SD = 0.27) from primary schools and high schools in the urban area of Geneva and 51 students from the University of Geneva (42 female; mean age = 24.5 years, SD = 2.07). Third, sixth, and ninth graders volunteered with parental informed consent, and university students participated for partial fulfillment of a course requirement. None of them took part in the main experiment. About half of the participants in each level performed the possibilities task (25 third, 22 sixth, and 24 ninth graders and 25 university students), and the other half completed the truth-value task. The same 4 (age group: third, sixth, and ninth grade and adults) × 2 (task: possibilities vs. truth-value) × 4 (type of case: $p \land q$, $\neg p \land q$, $p \land \neg q$, and $\neg p \land \neg q$) analysis of variance as in the main experiment was performed on the number of conditional responses. As we previously observed, apart from the effect of age resulting in a smooth increase in the rate of conditional responses (59%, 64%, 76%, and 87%) for the third, sixth, and ninth graders and adults, respectively), $F(3, 181) = 31.00$, $p < .001$, $\eta^2_p = .34$, there was a significant effect of tasks, with a higher rate of conditional responses in the possibilities task than in the truth-value task (75% and 68%, respectively), $F(1, 181) = 11.72$, $p < .001$, $\eta^2_p = .06$, which did not interact with age. The effect of cases was still significant, with $p \land q$ and $\neg p \land \neg q$ cases eliciting far more conditional responses (98% and 97%, respectively) than did the $\neg p \land \neg q$ and $p \land q$ cases (61% and 31%, respectively), $F(3, 543) = 309.88$, $p < .001$, $\eta^2_p = .63$, an effect that was qualified by age, $F(9, 543) = 17.34$, $p < .001$, $\eta^2_p = .22$, and by task, $F(3, 543) = 6.70$, $p < .001$, $\eta^2_p = .04$, whereas the Age × Task × Case interaction was not significant ($F < 1$).
and \(\neg p \neg q\) for a total of 16 trials. The presentation order of the trials was counterbalanced in such a way that two successive trials never presented the same logical case. Moreover, the 16 trials were presented in two different orders for both tasks; the first trial in one order was the last trial for the second order. In both tasks, the experimenter controlled when the next trial was initiated in order to make sure that all the participants had enough time to answer.

In the possibilities evaluation task, participants were told that a teacher had asked her 16 pupils to fill a box with a circle and a star. The teacher had given each pupil an instruction concerning the color of the circle and the star in the box. Participants were asked to look at each box and judge the contents according to the following instructions: “You must say whether the pupil complied with the rule or not. You must mark the green box if the pupil was correct and complied with the instruction, and the red box if the pupil did not comply with the instruction and was wrong.”

Concerning the truth-value evaluation task, the participants were informed that a teacher had filled five boxes for each of her 16 pupils. Each pupil received four of the five boxes. By studying the colors of the circle and the star in these four boxes, the pupils then had to guess which rule the teacher followed by filling the boxes. When watching the fifth box, the box that the pupil did not see, participants were asked to judge the truth-value of the putative rule: “By studying the contents of the box, you must say if the rule discovered by the pupil is true or false, or if the contents of the box does not permit you to know if the rule is true or false. You must mark the green box for responding “true,” the red box for responding “false,” and the blue box for responding “one cannot know.” For the control experiment, these instructions were restricted to the following: “By studying the contents of the box, you must say if the rule discovered by the pupil is true or false. You must mark the green box for responding “true” and the red box for responding “false.”

Results

Analyses of the Rate of Conditional Responses

The percentages of the different kinds of responses for the two tasks and for each age group are given in Table 2, in which the responses corresponding to a conditional interpretation in each task are indicated in bold. We performed a 4 (age group: third, sixth, and ninth grade and adults) \(\times 2\) (task: possibilities vs. truth-value) \(\times 4\) (type of case: \(pq\), \(p\neg q\), \(\neg p \neg q\), and \(\neg p q\)) analysis of variance (ANOVA) on the number of conditional responses as defined in Table 1, with the last factor as a within-subject variable. As we predicted, the possibilities task involved a higher rate of conditional responses than did the truth-value task (76% and 71%, respectively), \(F(1, 164) = 7.09, p < .01, \eta^2_p = .04\). There was also a main effect of age, with older participants producing more conditional responses, \(F(3, 164) = 63.54, p < .001, \eta^2_p = .54\), an effect that did not significantly interact with tasks, \(F(3, 164) = 2.14, p = .10\). There was also a significant effect of case, \(F(3, 492) = 175.94, p < .001, \eta^2_p = .52\). Not surprisingly, \(p\) cases elicited a higher rate of conditional responses than did \(\neg p\) cases (100%, 89%, 66%, and 41% for \(pq\), \(p\neg q\), \(\neg p \neg q\), and \(\neg p q\), respectively). This effect interacted with age, \(F(9, 492) = 17.64, p < .001, \eta^2_p = .24\), and with tasks, \(F(3, 492) = 2.67, p < .05, \eta^2_p = .02\); and the Case \(\times\) Age \(\times\) Task interaction was also significant, \(F(9, 492) = 5.10, p < .001, \eta^2_p = .09\). Separate analyses were performed for each type of case, with ages and tasks as between-subjects variables for both experiments.

Concerning the \(pq\) cases, there was no significant effect, with rates of conditional responses (i.e., “compatible” and “true” for the possibilities and the truth-value tasks, respectively) never being lower than 98%. By contrast, there was an effect of task on the rate of conditional responses to \(\neg pq\) cases (i.e., “incompatible” and “false”), with a higher rate in the possibilities task than in the truth-value task (93% and 84%, respectively), \(F(1, 164) = 8.21, p < .01, \eta^2_p = .05\). Moreover, this effect of task interacted with age, \(F(3, 164) = 4.74, p < .01, \eta^2_p = .08\). As can be seen in Figure 1, it was significant in third graders, \(F(1, 164) = 15.38, p < .001\), and decreased progressively with age. This was due to the presence of a pattern of responses that we described in previous studies as a matching pattern (Barrouillet et al., 2008; Gauffroy & Barrouillet, 2009). It consists in responding “true” for \(pq\) cases, “indeterminate” for \(pq\) and \(\neg pq\) cases, and false for \(\neg pq\) and \(\neg q\) cases, whereas the conditional response to \(\neg pq\) is “false.”

Because these matching responses disappeared progressively

Table 2

<table>
<thead>
<tr>
<th>Age group and task</th>
<th>(pq)</th>
<th>(\neg pq)</th>
<th>(\neg pq)</th>
<th>(\neg pq)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Truth-value</td>
<td>100</td>
<td>0</td>
<td>0</td>
<td>20</td>
</tr>
<tr>
<td>Possibilities</td>
<td>100</td>
<td>0</td>
<td>35</td>
<td>65</td>
</tr>
<tr>
<td>Grade 6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Truth-value</td>
<td>100</td>
<td>0</td>
<td>0</td>
<td>40</td>
</tr>
<tr>
<td>Possibilities</td>
<td>100</td>
<td>0</td>
<td>75</td>
<td>25</td>
</tr>
<tr>
<td>Grade 9</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Truth-value</td>
<td>99</td>
<td>1</td>
<td>0</td>
<td>84</td>
</tr>
<tr>
<td>Possibilities</td>
<td>100</td>
<td>0</td>
<td>89</td>
<td>11</td>
</tr>
<tr>
<td>Adults</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Truth-value</td>
<td>100</td>
<td>0</td>
<td>0</td>
<td>96</td>
</tr>
<tr>
<td>Possibilities</td>
<td>98</td>
<td>2</td>
<td>88</td>
<td>12</td>
</tr>
</tbody>
</table>

Note. Values in boldface correspond to the conditional responses. T/C = true/compatible, referring to the responses for the truth-value and the possibilities tasks, respectively; Ind = “indeterminate” response (“one cannot know”) in the truth-value task; F/Inc = “false” and “incompatible” responses, respectively.
Figure 1. Mean number of conditional responses (out of four) to the $p \neg q$, $\neg p \neg q$, and $\neg p q$ cases as a function of age group and task. Numbers in the x-axes indicate grade level. The panels titled “$\neg p \neg q$ control” and “$\neg p q$ control” show the results for the $\neg p \neg q$ and $\neg p q$ cases in the control experiment, where a two-response (i.e., “true”/“false”) truth-value task was used. See the text for the nature of the responses considered as “conditional” for each case as a function of the task. Asterisks indicate significant differences between tasks.
with age, the rate of conditional responses to \( p \rightarrow q \) cases increased progressively to reach the high rates observed with the possibilities task.

The two cases that were of interest for our hypotheses were the \( \neg p \rightarrow q \) and the \( p \rightarrow \neg q \), where the target responses were “compatible” and “irrelevant” for the possibilities and the truth-value tasks, respectively. Concerning \( p \rightarrow \neg q \) cases, apart from an age effect resulting from a strong developmental increase in conditional responses, \( F(3, 164) = 37.97, p < .001, \eta_p^2 = .41 \), the ANOVA revealed a significant effect of task, \( F(1, 164) = 5.81, p < .02, \eta_p^2 = .03 \), that interacted with age, \( F(3, 164) = 3.80, p < .02, \eta_p^2 = .07 \). Whereas the conditional responses to \( \neg p \rightarrow q \) cases were rare in third graders for both tasks, their rate strongly increased between third and sixth grade for the possibilities task, whereas this increase was moderate for the truth-value task, resulting in a significant difference for sixth graders, \( F(1, 164) = 12.31, p < .001, \eta_p^2 = .07 \). This difference reflects the developmental lag we predicted. The conditional responses to \( \neg p \rightarrow q \) cases became predominant in sixth graders reflect their access to the biconditional interpretation when evaluating possibilities, but their interpretation was still conjunctive when evaluating truth-values (see Figure 1). This difference disappeared in ninth graders where the reasoning about truth-values reached the biconditional level of interpretation, indicating that the developmental lag we predicted between the two kinds of reasoning is about 3 years.

The same phenomenon appeared for \( p \rightarrow q \) cases but later in development. The analyses revealed a complex developmental pattern with a significant effect of age, \( F(3, 164) = 32.39, p < .001, \eta_p^2 = .37 \), and no effect of task (\( F < 1 \)) but an interaction between the two factors \( F(3, 164) = 4.75, p < .01, \eta_p^2 = .08 \). This unexpected pattern was due to the fact that although the possibility task elicited a higher rate of conditional responses in ninth graders, \( F(1, 164) = 6.38, p < .02 \), the reverse effect was observed in third graders, \( F(1, 164) = 4.94, p < .05 \) (see Figure 1). This is another consequence of the matching patterns aforementioned. Whereas this pattern reflects a deep misunderstanding of the meaning of the conditional, it results in a response to the \( p \rightarrow q \) cases that corresponds to the elaborated response observed in the conditional interpretation (i.e., “indeterminate”). We thus ran the same analysis without the participants who adopted a matching strategy and who were identified from their responses to \( p \rightarrow q \) cases. As has been seen, the matching pattern leads to an “indeterminate” response instead of a “false” response to the \( p \rightarrow q \) cases. The participants who did not respond “false” on at least three out of the four \( p \rightarrow q \) cases were considered as adopting a matching strategy and were discarded from the analysis (5 third graders, 4 sixth graders, and 1 ninth grader). As Figure 1 indicates, this procedure revealed a clearer developmental trend. When matching responses were excluded, the conditional responses to the \( p \rightarrow q \) cases were rare for both tasks in third and sixth graders. The conditional response became predominant in ninth grade for the possibilities task but not for the truth-value task, \( t(36) = 2.35, p < .05 \), whereas there was no significant difference in adults. The difference in ninth graders reflected a shift from the biconditional to the conditional interpretation in reasoning about possibilities but not truth-values. In summary, the analyses of responses to each case revealed the predicted developmental lag, with the shift from one interpretational level to the next occurring earlier when reasoning about possibilities.

**Control Experiment**

These conclusions were confirmed by the control experiment, which provided convergent and even clearer results (see Table 3). Indeed, because participants had to decide between only two possible responses in the truth-value evaluation task (i.e., “true” and “false”), the matching patterns previously observed disappeared. As a consequence, and as we predicted, the responses to \( p \rightarrow q \) and \( p \rightarrow q \) cases no longer varied across age or conditions, with high rates of conditional responses (between 95% and 100% for \( p \rightarrow q \) and between 93% and 98% for \( p \rightarrow q \)). Concerning \( \neg p \rightarrow q \), there was still a strong effect of age, \( F(3, 181) = 14.23, p < .001, \eta_p^2 = .19 \), as well as an effect of task, \( F(1, 181) = 13.10, p < .001, \eta_p^2 = .07 \), with no interaction between the two factors. These cases were more often judged as compatible with the conditional sentence than they were judged as making it true. However, this effect that was significant in sixth graders, \( F(1, 181) = 4.19, p < .05 \), did

<table>
<thead>
<tr>
<th>Table 3</th>
<th>Percentage of Each Type of Response in Each Age Group for the Two Tasks in the Control Experiment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( p \rightarrow q )</td>
</tr>
<tr>
<td>Age group and task</td>
<td>T/C</td>
</tr>
<tr>
<td>Grade 3</td>
<td>Truth-value</td>
</tr>
<tr>
<td></td>
<td>Possibilities</td>
</tr>
<tr>
<td>Grade 6</td>
<td>Truth-value</td>
</tr>
<tr>
<td></td>
<td>Possibilities</td>
</tr>
<tr>
<td>Grade 9</td>
<td>Truth-value</td>
</tr>
<tr>
<td></td>
<td>Possibilities</td>
</tr>
<tr>
<td>Adults</td>
<td>Truth-value</td>
</tr>
<tr>
<td></td>
<td>Possibilities</td>
</tr>
</tbody>
</table>

*Note.* Values in boldface correspond to the conditional responses. T/C = true/compatible, referring to the responses for the truth-value and the possibilities tasks, respectively; F/Inc = “false” and “incompatible” responses, respectively.
not disappear, remaining significant in ninth graders, $F(1, 181) = 4.91, p < .05$, and even in adults, $F(1, 181) = 4.93, p < .05$ (see Figure 1). This suggests that, when they could not use the “one cannot know” response, many adolescents and adults deemed the conditional false for $\neg p \neg q$, hence remaining at a conjunctive level, which the following response pattern analysis makes clear. The analysis of the responses to $\neg p q$ cases replicated what we previously observed when the participants who adopted a matching strategy were removed: Ninth graders gave more conditional responses to $\neg p q$ cases with the possibilities task (i.e., “compatible”) than with the truth-value task (i.e., “true”), $F(1, 181) = 12.45, p < .01$. This difference was not observed in the other age groups (see Figure 1). In summary, the control experiment confirmed the existence of a developmental lag between reasoning about possibilities and reasoning about truth-values. This delay was better illustrated by a pattern-response analysis. We in turn present this analysis for the main experiment and then for its control.

Response Pattern Analyses

In both tasks, each participant was classified according to the interpretation that underpinned his or her answers. The responses corresponding to the conjunctive, biconditional, and conditional interpretations are given in Table 1. For the truth-value task, we added the aforementioned matching pattern to this analysis (“true” for $pq$, “indeterminate” for $\neg p q$ and $p \neg q$, and “false” for $\neg p \neg q$). A participant was considered consistent in a given interpretation if at least three out of four responses for each case ($pq$, $\neg p q$, $\neg p q$, and $p \neg q$) were consistent with this interpretation. Interestingly, this procedure permitted us to classify more than 90% of the participants in each age group and for each task (mean of 94%) as consistent, demonstrating that the participants were highly consistent in their responses. First, this analysis confirmed that, in both tasks, the interpretation of conditional evolves with age from a conjunctive to a biconditional and then a conditional interpretation (see Figure 2). We also observed that the truth-value task elicited...
matching patterns in the younger groups, with more than 20% of the third graders endorsing this strategy. The presence of matching patterns indicates clearly how difficult it is for children to reason about the truth-value of conditionals. However, and most important, this analysis clearly illustrates the developmental lag between the two kinds of reasoning. The predominant interpretation, which is conjunctive for both tasks in third graders, moves to a biconditional interpretation for the possibilities task in sixth graders, with more than 70% of them endorsing it. However, this shift does not occur for the truth-value task, with the modal interpretation remaining conjunctive in the sixth grade. It is only with ninth graders that the biconditional interpretation prevails in thinking about truth-value, whereas at this age the modal interpretation is already conditional when thinking about possibilities. Our results suggest that this conditional interpretation is reached only in adulthood when reasoning about truth-values. This developmental lag gives rise to striking phenomena. For example, although sixth graders consistently judged the \( \neg p \land \neg q \) cases as compatible with the conditionals, they considered these same cases as falsifying the same sentences in 60% of the trials. In the same way, ninth graders gave a majority of "compatible" responses to the \( \neg p \land q \) cases, but they deemed the conditional false for the same cases in more than 60% of the trials. It is only among adults that these cases were no longer considered as falsifying the conditional (less than 40% gave "false" responses).

Other interesting phenomena were also observed. It can be seen that even if the conditional interpretation finally prevails in adults when thinking about truth-value, it remains less frequent than when thinking about possibilities. In line with the hypothesis of a developmental lag, many adults and ninth graders regressed to the previous developmental stage (i.e., biconditional) when thinking about truth-values. Interestingly, the rate of conjunctive responses remained roughly stable from one task to the other for these age groups.

**Response Pattern Analyses of the Control Experiment**

The possibilities task and its expected response patterns remained unchanged in the control experiment. By contrast, the three developmental levels would result in specific response patterns in the two-alternative truth-value task: The conjunctive interpretation would lead to a "true" response for \( p \land q \) and "false" for all other cases. The biconditional interpretation would be characterized by "true" responses for \( p \land q \) and \( \neg p \land \neg q \) cases and "false" for the others. Finally, the conditional interpretation would lead to a "true" response to \( p \land q \), \( \neg p \land \neg q \), and \( \neg p \land q \) cases and "false" for the sole \( p \land \neg q \) cases. This last response pattern corresponds to the interpretation known as the material implication. We used the same criterion of consistency, with three out of four similar responses. Participants were highly consistent in their responses, with more than 90% classified as consistent in each age group and for each task. The analysis on the possibilities task replicated the results previously observed, with a developmental trend from a conjunctive interpretation predominant in third graders to a biconditional interpretation favored by sixth graders. The conditional interpretation became predominant in ninth graders and adults (see the "Possibilities control" panel in Figure 2). This development was delayed with the truth-value task, with a predominant interpretation that was still conjunctive in sixth graders and biconditional in ninth graders (see the "Truth-value control" panel in Figure 2). However, and contrary to what we previously observed, the decrease in conditional patterns in ninth graders did not result in an increase in the number of biconditional interpretations; rather, the number of conjunctive interpretations increased. This also occurred in adults, with almost 30% of participants being consistent in a conjunctive interpretation. This phenomenon, which echoes previous findings from other tasks that required participants to evaluate the truth of conditionals and, more precisely, their probability (Evans, Haddlely, & Over, 2003), is discussed later. Nonetheless, the same succession of conjunctive, biconditional, and conditional interpretations appeared in the truth-value task but with a systematic lag when compared with the possibilities task. Thus, the control experiment confirmed the results previously observed, giving strong support to our hypotheses.

**Discussion**

The aim of this study was to explore the developmental consequences of the main tenet of the mental model theory, which is that, when individuals reason, they think about possibilities (Johnson-Laird, 2006). If representing possibilities is a basic process, then those forms of reasoning consisting of judging what is possible given the truth of a sentence should be easier and develop earlier than when reasoning the other way around and judging the truth of a sentence from a given state of affairs. Two experiments corroborated these predictions. Reasoning about possibilities and reasoning about truth-values follow the same developmental trend from a conjunctive to a biconditional and then a conditional reading of the conditional. However, the reasoning about truth-values is developmentally delayed for several years. These findings have strong implications for understanding these forms of reasoning and their development.

**Reasoning About Possibilities**

Considering reasoning about possibilities from the unfamiliar relations we used, which do not allow for the use of knowledge or previous experience, children move from a conjunctive to a biconditional interpretation around sixth grade, that is, at the beginning of adolescence. This development is significant because it reveals that, contrary to the case with third graders, who cannot admit the possibility of cases in which \( p \) would be false, young adolescents begin to grasp the suppositional meaning of the conditional and understand that \( \neg p \) cases are not necessarily incompatible with the conditional. This developmental change, which opens the door to rational thinking about possibilities, echoes the access to the formal operational stage in Inhelder and Piaget’s (1958) theory. In the Piagetian reformulation of the mental model theory proposed by Markovits (1993), this change corresponds to the possibility for adolescents to produce alternative models to the initial representation \( p \land q \) in a purely verbal context without any recourse to episodic knowledge. This change could also illustrate the general developmental trend described by the fuzzy trace theory from verbatim to gistified representations (Brainerd & Reyna, 2001). Whereas children adopt mainly a conjunctive interpretation, in which they take into account only the explicit content of the conditional sentence (i.e., the co-occurrence of \( p \) and \( q \)), adolescents go beyond this verbatim representation and envision other possibilities. In a first step, they consider only \( \neg p \land \neg q \) cases as compatible with the conditional, whereas \( \neg p \land q \) cases are still considered as incompatible. A further change occurs later, in our
experiment around ninth grade, when adolescents were able to go beyond the biconditional interpretation and understand that \( \neg p \land q \) cases are also compatible with the conditional.

**Reasoning About Truth and Falsy**

The present study reveals that these same changes also occur for reasoning about truth-value but three years later. Even though this developmental lag occurred in both experiments, reducing the possible responses in the truth-value task to a true/false alternative had interesting consequences. This task elicited conjunctive response patterns in older adolescents and adults that were practically never observed in the three-response version (see Table 2). When comparing the responses given by ninth graders and adults in the two truth-value tasks, it appears that the rate of conjunctive response patterns increased in the control experiment mainly at the expense of the biconditional responses, whereas the rate of conditional patterns remained quite stable. This suggests that most of the participants, who had probably considered the conditional as indeterminate for both \( \neg p \land q \) cases in the three-response task, deemed it true for both cases when restricted to the true/false alternative, thus exhibiting a conditional response. By contrast, participants who would have deemed the truth-value of the conditional indeterminate for \( \neg p \land \neg q \) and false for \( \neg p \land q \) in the three-response task, thus exhibiting a biconditional interpretation, considered both cases made the conditional false when their choice was restricted to two possibilities, as if there were a phenomenon of contamination between \( \neg p \) cases. This could explain why the biconditional interpretations were rarer in the older participants when thinking about truth-values in the control experiment even though it was still the modal interpretation in ninth graders.

It can be noted that this phenomenon of contamination between \( \neg p \) cases is less pronounced in younger participants, who did not produce fewer biconditional responses with two than with three possible responses in the truth-value task. This means that the children and young adolescents who would deem the conditional indeterminate for \( \neg p \land \neg q \) and false for \( \neg p \land q \) in the three-response task were prone to consider it true for \( \neg p \land \neg q \) but false for \( \neg p \land q \). This difference between our young and older participants in their sensitivity to the number of responses offered by the truth-value task could reflect a developmental increase in the capacity to reach an integrated conception of the conditional in which the truth-values for each logical case are seen as a structured and complete system. Being better able to construct such an integrated representation, older participants would tend to avoid different values for \( \neg p \) cases. Consequently, both \( \neg p \) cases were judged as making the conditional either true or false, resulting in conditional or conjunctive responses. This does not mean that many adults have a real conjunctive understanding of the conditional. Indeed, conjunctive patterns were exceptional at this age level in the possibilities task and never observed in the three-response truth-value task. It is interesting that Evans et al. (2003) observed approximately the same rate of conjunctive interpretations in adults when solving a probability task. When asked to evaluate the probability of an \( \text{If } p \text{ then } q \) conditional being true or false, about one third of adults gave the probability of the conjunction \( p \land q \). This suggests that the phenomena we observed here with a truth-value task probably extend to all the tasks in which participants are asked, directly or indirectly, to evaluate the truth-value of the conditional.

**The Development of the Two Forms of Reasoning**

Inhelder and Piaget (1958) considered propositional reasoning, like conditional reasoning, to be a manifestation of formal thinking that is not available before adolescence. As Markovits and Barbouillet (2002) noted, the studies that have attempted to examine young children’s capacity to think “logically” about conditionals have led to mixed results. Some of them indicated developmental trends compatible with a Piagetian hypothesis (Byrnes & Overton, 1988; Markovits & Vachon, 1989, 1990; O’Brien & Overton, 1980; Ward & Overton, 1990), whereas others revealed precocious reasoning abilities (see e.g., Dias & Harris, 1990; Perner, Sprung, & Steinkogler, 2004). One of the reasons for these seemingly contradictory results is probably that these different studies differed in the tasks used, the content and context of the problems involved, and the nature of the responses expected. For example, young children exhibit reasoning capacities when thinking about familiar or socially relevant contents (see e.g., Harris & Nunez, 1996; Markovits, Fleury, Quinn, & Venet, 1998; Markovits & Thompson, 2008). There is also evidence that they can reason about unfamiliar or even counterfactual contents when presented in a context of fantasy (Dias & Harris, 1988, 1990) or when problems involve simple scenarios (Perner et al., 2004). Nonetheless, these studies usually involve reasoning about possibilities.

Most often, young children are asked to identify cases inconsistent with a rule or to assess simple inferences by exploring their own knowledge base (Harris & Nunez, 1996; Markovits & Thompson, 2008; Markovits et al., 1998). As noted by Rafetseder, Cristi-Vargas, and Perner (2010), most of these early successes could be based on basic conditional reasoning requiring only memory retrieval or a simple logical reasoning rule of universal instantiation. Similarly, when reasoning about unfamiliar contents in a fantasy context, children were asked to evaluate possibilities in isolation (Dias & Harris, 1988, 1990). This differs from the way Piaget understood logical thinking, that is, as the capacity to integrate and coordinate all possible inferences within a system of rational transformations.

When the studies systematically investigated the understanding of conditional statements involving unfamiliar relations through the entire set of possible cases or inferences, a different picture appears. Conditional reasoning proves to be late in development, the final developmental levels not yet reached until late adolescence (Barrouillet et al., 2000; Barrouillet & Lecas, 1998, 2002). Our results replicated these observations: It is not before the age of 12 years (Grade 6) that the majority of children understand that cases other than \( p \land q \) are compatible with the conditional. Furthermore, it is only around the age of 16 years that adolescents reach a conditional interpretation whereby \( p \leftrightarrow \neg q \) is the sole case incompatible with \( \text{If } p \text{ then } q \) sentences. These results are in line with Piaget's hypothesis, but it could be considered surprising that reasoning about truth-values develops even later. In fact, this developmental difference is not at odds with Piaget’s theory.

When investigating the development of possibility and necessity in one of his last works, Piaget (1987) assumed that the capacity to produce possibilities does not depend on, but precedes the construction of, operations on which rational thinking is based. In some sense, this idea is akin to Johnson-Laird’s (2006) proposal that constructing possibilities is the fundamental process on which any reasoning is based. According to Piaget, this generation of
possibilities constitutes a diversification of what is immediately accessible in the real world (e.g., in our tasks, the conjunction of \( p \) and \( q \) given in the conditional sentence) and a source of disequilibrium. This movement of opening the range of possibilities leads to an infinite process of assimilation that requires a correlative movement of closure by integration of these possibilities, a closure that is assumed to reveal necessity. The developmental lag observed in the present studies suggests that this integration is a late achievement that does not coincide with the production of possibilities. It has been seen that, during all of adolescence, some states of affairs can be considered as possible given the truth of the conditional sentence, whereas these states of affairs are considered as falsifying this conditional when they occur. This paradox probably occurs because reaching a coherent understanding of the conditional necessitates first to integrate all the possible cases in a unique structure. This integrated structure would make children aware that those cases that are compatible with the sentence cannot make it false. Judging the possibility or impossibility of a given state of affairs according to a rule can be achieved by focusing on this state of affairs alone. What is needed in this task is the use of similarities and differences with the representation constructed, which are processes involved in the creation of possibilities according to Piaget. By contrast, evaluating the truth-value of a sentence from states of affairs necessitates consideration of the relationships between all the possible cases to classify them into those that make the sentence true and those that make it false. This requires explicit affirmations and negations, which are operations in Piagetian terms. This process was clearly apparent in our older participants when thinking about truth-values with only the true and false options. They tended to produce coherent response patterns in which the same response was given to both \( \neg p \) cases, probably by creating equivalences of the form not false = true or not true = false. This was not observed with the younger participants.

With the exception of obvious differences at the epistemological and functional levels, Piaget’s (1987) conception of the possible and its development is not so far from the mental model approach. Johnson-Laird and Byrne (2002) assumed that, contrary to judging what is possible, the judgment of the truth or falsity of assertions containing connectives is a meta-ability, because the metalinguistic predicates true and false refer to relations between assertions and the world. Our Piagetian reanalysis of this idea suggests that the judgment of the truth or falsity is a meta-ability because it necessitates an integration of all the possibilities constructed into a unique and coherent structure. This integration constitutes a further developmental step beyond the mere construction of possibilities that explains the developmental lag we observed.

Johnson-Laird and Byrne’s (2002) reference to a meta-ability echoes another theoretical proposal that can enlighten the difference between the two forms of reasoning we studied, namely, Moshman’s (1990) theory of the development of metalogical understanding. Moshman claimed that, despite the evidence of reasoning capacities in preschoolers and of some pervasive illogicality in the performance in adults (see e.g., Evans, 1982), logical reasoning improves with age, not only in the weak sense of exhibiting age-related changes but in the stronger sense of progressing toward greater rationality. Moshman distinguished four different stages in the development of metalogic understanding, the two latter—explicit logic–implicit metalogic and explicit metalogic—being of interest here. The Stage 3 explicit logic–implicit metalogic is described as beginning around age 11 and is characterized by a capacity to reason about the logical form of propositions from the metalogical perspective of a formal logical system. However, at this stage, children cannot think about such a system and take it as an object of understanding. This is what we observed in the present studies. From Grade 6 onward, adolescents were able to go beyond the explicit content of the conditional statement to envision that cases other than \( p \) and \( q \) are possible and compatible with the conditional. By the age of 15 in the ninth grade, most of them grasped the meaning of the conditional connective and understood that three cases were permissible. As we have argued elsewhere (Barrouillet et al., 2008), this representation reflects a logical system that is not so far from the meaning of the conditional within formal logic. As such, the development we observed in reasoning about possibilities perfectly corresponds to an explicit-logic stage. However, as Moshman described, adolescents are not yet able to think about this system, something that necessitates a higher developmental level and a fourth stage of explicit metalogic. We argue that explicit metalogic is precisely what the truth-value task requires. Indeed, Moshman assumed that it is only at this fourth stage that individuals can think about the logical system as a system and grasp its relationships with natural language, something clearly needed by the truth-value task. Thus, the developmental lag between reasoning about possibilities and reasoning about truth-value would correspond to the gap between two successive stages in the development of reasoning. Moshman assumed that most people would probably never achieve the fourth stage. Actually, even when the range of possibilities was restricted to two values in the truth-value task, only 62% of university students gave a response pattern entirely consistent with the prescriptions of formal logic (i.e., the material implication), even though these individuals were probably among the most skilled within the entire population.

Concluding Comments

The present study has demonstrated that, as the mental model theory assumes, thinking about possibilities is easier and develops earlier than does thinking about truth-values. Of course, we used only one task to assess reasoning about possibilities, and this possibilities evaluation task could be considered as tied to the mental model theory. Thus, further studies are needed to extend and strengthen the present results with less theory-specific tasks. Nonetheless, the fact that both forms of reasoning exhibit the same succession of interpretational levels with a developmental lag suggests that the development of reasoning goes further than a mere age-related evolution in the structural complexity of the representations that children and adolescents can construct. Such an increase in the complexity of representations was advocated by most of the neo-Piagetian theories (Case, 1992; Halford, 1993; see for a review Morra, Gobbo, Marini, & Sheese, 2008) as well as by many developmental theories of conditional reasoning (see e.g., Gauffroy & Barrouillet, 2009; Markovits, 1993; Markovits & Barrouillet, 2002). The developmental lag between the two forms of reasoning observed here reveals that beyond this cognitive development, the progression toward higher levels of rationality also necessitates the construction of meta-abilities that are required to think about truth and falsity. This metacognitive development
was the main attribute of the formal operations described by Piaget (1987), operations that consist of taking the operations of the former stages as object of knowledge. Accordingly, our results indicate that this later level is achieved only at the end of adolescence, as Moshman (1990) surmised with his theory of an explicit metalogic stage. This delineates a development of reasoning and rationality that encompasses the entire span of the developmental period, with the first rational thoughts already observed in young children whereas the later achievements occur only at the edge of adulthood.

References


Received April 19, 2010
Revision received October 28, 2010
Accepted November 24, 2010