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Conditional reasoning in context: A developmental dual processes account

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The way individuals interpret “if *p* then *q*” conditionals varies with content and context, often resulting in a biconditional reading. Surprisingly, truth table tasks reveal the existence of two different types of biconditional interpretations: equivalence, as for promises and threats, and defective biconditional, as for causal conditionals or indicative conditionals involving binary terms. The aim of this study was to determine how the interpretation of indicative conditionals is affected in children, adolescents, and adults, by restricting their context of enunciation to only one possible alternative for both the antecedent and the consequent. Moreover, we wanted to determine what is the exact nature of the biconditional interpretation induced by these restricted contexts. For this purpose, third, sixth, and ninth graders and adults performed a truth-value task on indicative conditionals presented either in restricted or non-restricted contexts. Restricted contexts had no effect on children who have a conjunctive interpretation of the conditional, but elicited a predominant defective biconditional reading in adolescents and adults. These results corroborate the developmental dual process account of conditional reasoning proposed by Gauffroy and Barrouillet (2009).

Keywords: Conditional reasoning; Mental models; Heuristic and analytic processes; Context effect.

Conditional reasoning is the reasoning permitted by sentences containing the connector *If* (i.e., “If ... then ...”, “... only if ...”, “If only if ... then ...”). *If* (and the equivalent words in the other natural languages) is one of the most important words because it permits human to engage in hypothetical thinking which is an essential part of reasoning and decision making (Evans & Over, 2004). Accordingly, how people reason from *If* sentences

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and how this kind of reasoning develops with age have always been challenging questions for psychology. Interestingly, from the very first investigations it appeared that the context of enunciation has a great influence in the way conditional sentences are interpreted. For example, Fillenbaum (1975), following Geis and Zwicky (1971), observed that certain inferences, though not logically necessary, are invited by the context and strongly modify the meaning of the connector *if*. For example, threats and promises such as

If you mow the lawn, then I will give you 5 €

strongly invite the inference that if you don't mow the lawn, then I won't give you 5 €, thus resulting in a biconditional interpretation. However, this is not true for all conditional sentences, and universal or indicative conditionals like

If an animal is a dog, then it has four legs

does not invite the inference that if an animal is not a dog, then it does not have four legs. This led Fillenbaum (1975, p. 245) to conclude that "it is not reasonable to suppose that the conditional has some unique cognitive representation".

It is worth to note that the meaning of conditionals varies not only with their type, but also with slight variations in their content. For example, Barrouillet and Lecas (2002) observed that the introduction of binary terms in the antecedent and consequent of an indicative conditional results in more frequent biconditional interpretations. Binary terms are terms that allow for only one alternative such as in "if the light is lit, then the door is open", where "lit" and "open" only admit "off" and "closed" respectively as alternatives. Barrouillet and Lecas called these sentences BB (for Binary / Binary) conditionals, which were contrasted with NN (for Non-binary / Non-binary) conditionals which allow for several alternatives (e.g., "If the car is blue, then it is a Peugeot"). Barrouillet and Lecas (2002) went further in demonstrating that the same effect could be obtained with NN conditionals when embedded in a context that restricts to only two the possible values on both the antecedent and the consequent. These NN conditionals presented in a restricted context were called NNR conditionals. For example, the context of the NN conditional "If the car is blue, then it is a Peugeot" was restricted by informing participants that, in the garage, there are only two car brands, Peugeot and Citroën, and two possible colours, blue or red. As Barrouillet and Lecas predicted, NNR conditionals had the same effect as BB conditionals and elicited more biconditional interpretations than NN conditionals.

It could be concluded from these findings that promises, threats, BB, and NNR conditionals all induce the same biconditional interpretation but, as surprising as it may seem, this is not the case. We recently observed that children and adults do not associate the same truth tables with promises and threats on the one hand, and with BB conditionals on the other (Gauffroy & Barrouillet, 2009). We had children (third graders), adolescents (sixth and ninth graders), and adults (undergraduate students) to perform a truth table task on promises, threats, NN, and BB conditionals. They were asked to judge whether each of the four logical cases (i.e., $p \ q$, $\neg p \ \neg q$, $\neg p \ q$, and $p \ \neg q$) made the conditional sentences true, false, or if the case under study did not inform about their truth or falsity. With NN conditionals we observed the well-established developmental trend from a conjunctive to a biconditional and then a conditional interpretation (see Barrouillet, Grosset, & Lecas, 2000; Barrouillet & Lecas, 1998, 2002). More precisely the biconditional reading was actually a defective biconditional in which the truth value of the conditional remains indeterminate for the $\neg p \ \neg q$ case, and the last developmental level was a defective conditional interpretation with the truth value of the sentences remaining indeterminate for both $\neg p \ \neg q$ and $\neg p \ q$ cases (Table 1). Promises and threats elicited in all age groups a biconditional interpretation that took the form already observed by Newstead, Ellis, Evans, and Dennis (1997) of an equivalence reading in which both $p \ q$ and $\neg p \ \neg q$ cases make these inducements true whereas $\neg p \ q$ and $p \ \neg q$ cases make them false. However, although BB conditionals also elicited, as we expected, a biconditional interpretation even in adults, this interpretation did not take the form of an equivalence reading but of a defective biconditional reading in which $\neg p \ \neg q$ cases no longer make the conditional true, but leave its truth value indeterminate (Figure 1). Unfortunately we did not test NNR conditionals in this previous study. The aim of the present experiment was to investigate how the evaluation of the truth-value of a conditional could be modulated by its context of enunciation.

We will base our predictions and analyses on a model that we have recently proposed, which combines the mental model theory (Johnson-Laird

TABLE 1
Main interpretations observed in the truth-value evaluation task

Logical cases	Interpretations			
	Conjunctive	Defective biconditional	Defective conditional	Equivalence
$p \ q$	True	True	True	True
$\neg p \ \neg q$	False	Indeterminate	Indeterminate	True
$\neg p \ q$	False	False	Indeterminate	False
$p \ \neg q$	False	False	False	False

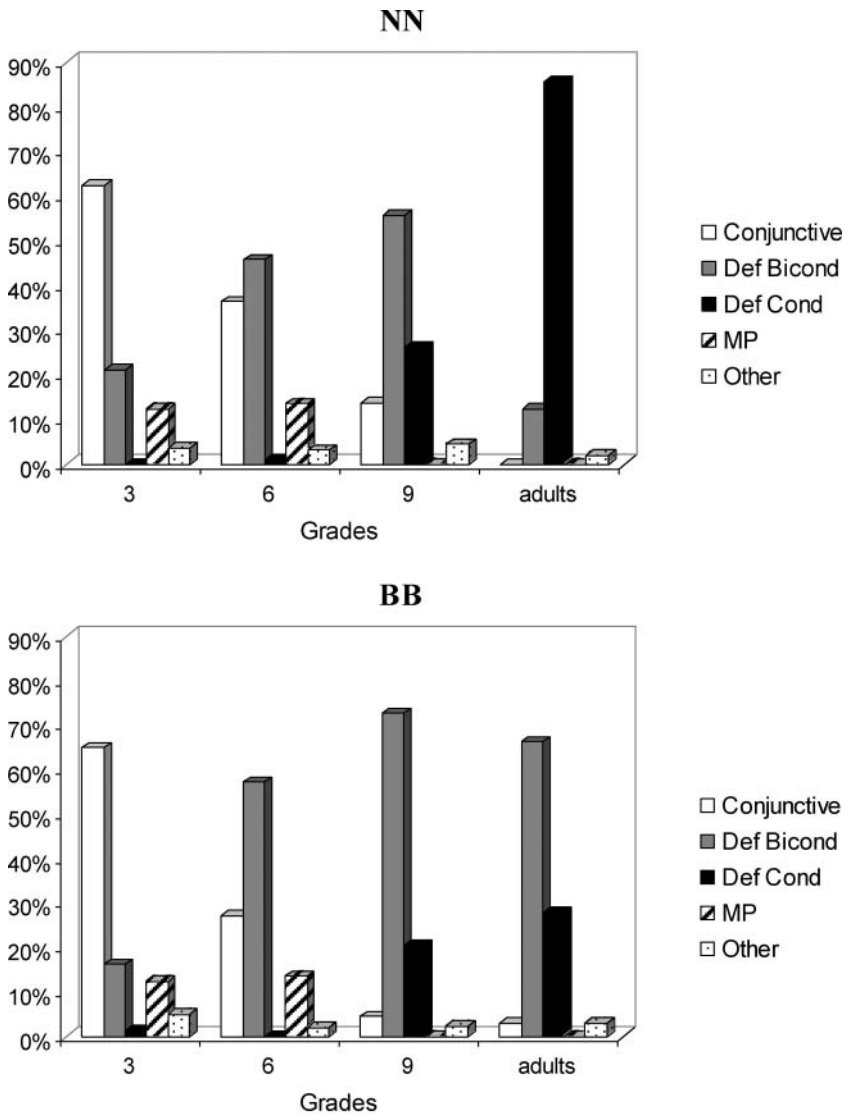


Figure 1. Percent of response patterns categorised as conjunctive, defective biconditional (Def Bicond), defective conditional (Def Cond), matching (MP) and others as a function of grades for NN and BB conditionals in Gauffroy and Barrouillet (2009).

& Byrne, 1991, 2002) with Evans' (2006) heuristic-analytic theory and applies the opposition between heuristic and analytic processes to the construction of mental models (Gauffroy & Barrouillet, 2009). According to the

mental model theory, when confronted with a conditional people first construct an initial model that refers explicitly to a state of affairs in which both the antecedent and the consequent are verified (e.g., a blue Peugeot for the NN conditional evoked above). Our theory assumes that this model, which comes spontaneously to mind, would be constructed through heuristic, tacit, and unconscious processes. Moreover, conscious and demanding analytic processes may or may not intervene to flesh out this initial model by representing other possibilities compatible with the conditional (the $\neg p \neg q$ and $\neg p q$ models). Our theory assumes that the three developmental levels described above depend on the efficiency of these analytic processes. Children who are not able to flesh out their initial model construct a representation involving the sole initial $p q$ model resulting in a conjunctive interpretation. Adolescents usually reach a biconditional interpretation by adding a $\neg p \neg q$ model, whereas adults often adopt a complete three-model representation by producing two additional models, $\neg p \neg q$ and $\neg p q$. One of the main assumptions of our theory concerns the epistemic status of these different models. The initial model that comes spontaneously to mind through heuristic processes appears psychologically as the core meaning of the sentence. Thus those states of affairs that match this initial model are judged as making the conditional true. By contrast, the states of affairs corresponding to models constructed through fleshing out by optional analytic processes are not considered as making the conditional true (they do not pertain to its core meaning), but do not falsify it because they are nonetheless compatible with it. Consequently they are judged as irrelevant for judging its truth value that remains indeterminate. Those cases that do not match any of the models constructed are judged as falsifying the conditional.

This theory explains why the age-related increase in the efficiency of the analytic processes results in a developmental trend from a conjunctive to a defective biconditional and then a defective conditional interpretation when evaluating the truth value of conditionals. Young children who construct the sole $p q$ model deem the conditional true for $p q$ cases and false for any other possibility. Adolescents who add to their initial representation the $\neg p \neg q$ model through fleshing out consider that cases matching this model leave indeterminate the truth value of the conditional that is still false for $\neg p q$ and $p \neg q$ cases, whereas older adolescents and adults who construct the $\neg p \neg q$ and $\neg p q$ models through fleshing out adopt a De Finetti truth table in which the conditional is true for $p q$, indeterminate for the $\neg p$ cases and false for $p \neg q$. The same theory accounts for the defective biconditional interpretation induced by BB conditionals. Barrouillet and Lecas (1998) assumed that binary terms affect the fleshing out process by restricting the semantic spaces from which values can be retrieved to construct alternative models. Because there is only one alternative value for the antecedent and the consequent,

the construction of the $\neg p \neg q$ model through fleshing out leads to a representation that Barrouillet and Lecas (1998) called *complete*. This representation establishes a one-to-one correspondence between the possible values of the antecedent and the consequent (lit – open, off – closed), blocking the construction of any further model (e.g., $\neg p q$). Because they match a model constructed through fleshing out, $\neg p \neg q$ cases are consequently considered as leaving the conditional indeterminate while $\neg p q$ cases that do not correspond to any constructed model make it false. This theory also accounts for the equivalence reading elicited by inducements like promises and threats. Evans, Newstead, and Byrne (1993) noted that for a promise like *If you mow the lawn, then I will give you 5 €*, the invited inference *if you don't, I won't give you 5 €* is part of its core meaning because the speaker wants the action accomplished and if there was a way for the hearer to get the 5 € without mowing the lawn, the speech act would lose its efficiency. Thus the invited inference being an essential element of the meaning conveyed by the promise, we assume that it is represented as a $\neg p \neg q$ model that is part of the initial representation along with the $p q$ model. Consequently, cases matching these models make the promise psychologically true, whereas it is falsified by $p \neg q$ and $\neg p q$ cases that contradict the initial promise and its invited inference respectively, resulting in the equivalence reading.

Concerning the interpretation of the NNR conditionals, what remained unclear with Barrouillet and Lecas (2002) study is the exact nature of the biconditional interpretation they elicited (either equivalence or defective biconditional). Barrouillet and Lecas favoured the equivalence hypothesis. They observed that NNR conditionals elicited a lower rate of MP and AC inferences than BB conditionals and, following Byrne and Tasso (1999), they interpreted these lower rates as resulting from an heavier initial representation containing two models ($p q$ and $\neg p \neg q$) instead of one ($p q$). However, this interpretation remained speculative and the inference task used did not allow for a distinction between equivalence and defective biconditional interpretations. It should be recalled that NNR conditionals were intended to artificially restrict to two the number of possible alternatives, as binary terms do, with the same restrictive effect on the fleshing out process that would be blocked after the construction of the $\neg p \neg q$ model. We have already observed that binary terms induce defective biconditional readings (Gauffroy & Barrouillet, 2009). Consequently we expected the same effect from restricted contexts. To test this hypothesis, we proposed to third, sixth, and ninth graders and adults a truth table task containing both NN and NNR conditionals. In line with Gauffroy and Barrouillet (2009), we predicted that the evaluation of NN conditionals should evolve from a conjunctive to a defective biconditional and then a defective conditional interpretation. Concerning NNR conditionals, if restricted contexts affect

analytic processes and fleshing out, two findings should be observed. First, restricted contexts should not affect those participants who are not able to flesh out the initial representation and exhibit a conjunctive interpretation. Consequently the rate of conjunctive interpretations should remain unchanged from NN to NNR conditionals. Second, NNR conditionals should induce the same interpretation as BB conditionals; that is, a defective biconditional reading that should remain predominant even in adults.

METHOD

Participants

A total of 21 third graders (mean age = 8.4 years, $SD = 0.5$, 12 females), 22 sixth graders (mean age = 12.1 years, $SD = 0.3$, 14 females), 24 ninth graders (mean age = 15.3 years, $SD = 0.6$, 15 females) from primary schools and high-schools in the urban area of Geneva, and 26 students from the University of Geneva (mean age = 22.1, $SD = 0.8$, 19 females) performed a truth table task containing both NN and NNR conditionals. Third, sixth, and ninth graders participated as volunteers, and students for partial fulfilment of a course requirement.

Materials and procedure

The truth table task was administered to groups of about 10 participants using a video projector. A short scenario was displayed at the top of the screen and introduced the conditional statement. The introductory scenario for NNR conditionals specified only one alternative for both p and q whereas, for NN conditionals, the scenario did not contain any mention of alternative values. For example, the introductory scenario for the NNR conditional "If there is a rabbit, then there is a sparrow" was:

Paul works in a store that sells animals. In each cage, there is a mammal (rabbit or hamster) and a bird (parrot or sparrow). Paul looks at the cages and thinks that he has guessed how the animals are kept in cages. The guessed rule is as follows: "If there is a rabbit then there is a sparrow".

By contrast, for the NN conditional "If there is a B on the panel, then there is a 3" the scenario did not mention any alternative values for p and q and only stipulated that pupils have made panels with a letter on the left and a number on the right. Four NN and four NNR conditionals were associated with the four logical cases, resulting in 32 trials. For example, for the conditional "If there is a rabbit, then there is a sparrow", the presented cases took the form: "rabbit – sparrow" (i.e., $p \ q$), "rabbit – parrot" (i.e., $p \ \neg q$),

Paul works in a store that sells animals. In each cage, there is a mammal (rabbit or hamster) and a bird (parrot or sparrow). Paul looks at the cages and thinks that he has guessed how animals are kept in cages. The guessed rule is as follows:

If there is a rabbit then there is a sparrow

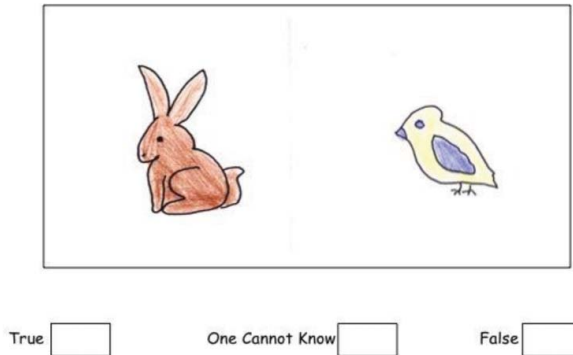


Figure 2. Example of material given to participants.

“hamster – parrot” (i.e., $\neg p \neg q$), and “hamster – sparrow” (i.e., $\neg p q$), whereas the corresponding cases for “If there is a B on the panel, then there is a 3” were B – 3, B – 7, T – 7, and T – 3 respectively. After 7 seconds a picture representing one of the four cases appeared under the statement (Figure 2), followed after 2 seconds by the three response possibilities (*true*, *false*, and *one cannot know*) that appeared under the picture. These possibilities of responses were also reported on the individual response sheets. Participants were asked to judge if the content of the box made the conditional true or false, or if one cannot know if the conditional was true or false. The eight problems were presented randomly. The experimenter controlled when the next trial had to be initiated to ensure that all the participants had enough time to answer.

RESULTS

Analyses of responses

The rate of *true*, *false*, and *one cannot know* responses for each of the logical cases on the two types of conditionals is presented in Table 2. In line with our predictions, $p q$ cases elicited in each age group a high rate of *true* responses for both NN and NNR conditionals. The ANOVA revealed no main effects of grades, type of conditional, and no interaction, $F_s < 1$.

TABLE 2
Percent of *true* (T), *one cannot know* (O), and *false* (F) responses for each logical case as a function of age group and type of conditional

Age groups	Conditionals	Cases											
		$p\ q$			$\neg p\ \neg q$			$\neg p\ q$			$p\ \neg q$		
		T	O	F	T	O	F	T	O	F	T	O	F
3 rd grade	NNR	99	1	0	0	32	68	0	15	85	0	13	87
	NN	98	0	2	0	27	73	0	15	85	0	19	81
6 th grade	NNR	97	1	2	1	64	35	1	15	84	1	15	84
	NN	99	0	1	0	56	44	1	16	83	0	15	85
9 th grade	NNR	99	1	0	0	95	5	0	23	77	0	0	100
	NN	98	1	1	1	86	13	0	37	63	0	0	100
adults	NNR	98	1	1	0	96	4	0	38	62	1	0	99
	NN	97	2	1	1	96	3	0	82	18	2	1	97

NNR corresponds to conditionals presented in restricted context and NN to conditionals presented in no-restricted context.

Concerning $p\ \neg q$ cases, *false* responses were predominant in each age group with no main effect of the type of conditional, $F(1, 89) = 1.03$, $p = .26$, and no interaction, $F(3, 89) = 1.04$, $p = .38$. However, as in our previous studies (Barrouillet, Gauffroy, & Lecas, 2008; Gauffroy & Barrouillet, 2009, 2011), the rate of *false* responses increased significantly with age, $F(3, 89) = 3.72$, $p < .05$. We argue that this effect was due to the occurrence of matching patterns in younger participants.¹

The two cases of interest were the false antecedent cases. Concerning $\neg p\ \neg q$, it is worth noting that no participant consistently considered that this case made the conditional true (less than 2% of responses). The $\neg p\ \neg q$ model would therefore not pertain to the initial representation but would correspond to a model constructed through fleshing out. Indeed, the rate of indeterminate responses on $\neg p\ \neg q$ cases increased significantly with age for both NN, $F(3, 89) = 19.68$, $p < .001$, and NNR conditionals, $F(3, 89) = 21.26$, $p < .001$. Neither the effect of the type of conditional, $F(1, 89) = 2.73$, $p = .10$, nor the interaction, $F < 1$, was significant.

Finally, as binary terms, the restricted context seemed to block the construction of the $\neg p\ q$ model for NNR conditionals. Consequently although

¹ The matching pattern consists in responding *true* when the two pictures match the antecedent and the consequent (i.e., $p\ q$), *one cannot know* when only one of the two propositions is verified (i.e., $p\ \neg q$ and $\neg p\ q$), and *false* when there is no match at all (i.e., $\neg p\ \neg q$).

the rate of indeterminate responses on $\neg p \rightarrow q$ cases increased with age for NN conditionals, $F(3, 89) = 18.35, p < .001$, there was no significant age effect for NNR conditionals, $F(3, 89) = 1.92, p = .13$, with a significant interaction between age and type of conditional, $F(3, 267) = 7.85, p < .001$.

Response patterns analysis

Response patterns were categorised for each of the eight conditionals studied according to the interpretations described in Table 1. We added the aforementioned matching pattern. Almost all the response patterns corresponded to one of these interpretations (more than 90%, Figure 3). First of

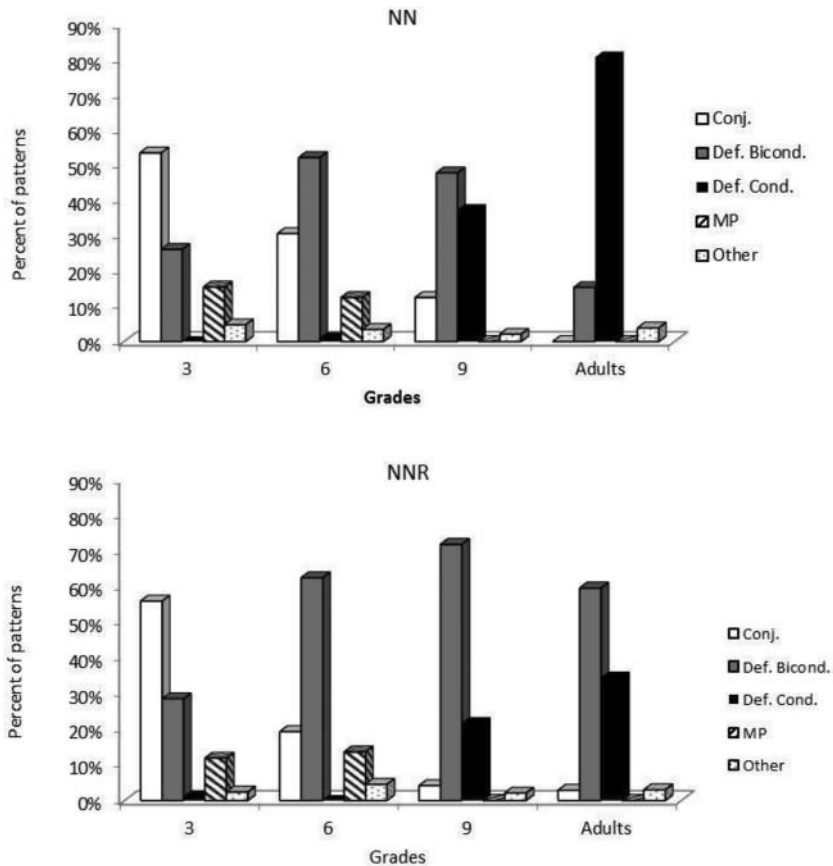


Figure 3. Percent of response patterns categorised as conjunctive (Conj), defective biconditional (Def Bicond), defective conditional (Def Cond), matching (MP), and others as a function of grades for NN and NNR conditionals.

all, it is worth noting that no equivalence interpretation was observed for both types of conditional.

For NN conditionals, the conjunctive interpretation was predominant in younger participants and decreased with age with a significant linear trend, $F(1, 89) = 30.42, p < .001$. The defective biconditional pattern constituted an intermediate level with a significant quadratic trend, $F(1, 89) = 11.64, p < .001$. Finally, the rate of defective conditional patterns increased linearly with age to become the main interpretation in adults, $F(1, 89) = 145.24, p < .001$.

As far as the NNR conditionals were concerned, the results clearly showed that restricting the context affected the fleshing out of the $\neg p \ q$ model. As we predicted, the restricted contexts did not affect the rate of conjunctive responses, $F(1, 89) = 1.23, p = .27$, which remained predominant in the youngest participants (56% in third graders). Restricting the context induced an increase in the rate of defective biconditional patterns (35% and 56% for NN and NNR conditionals respectively), $F(1, 89) = 19.12, p < .001$. This response was predominant from sixth grade to adulthood.

DISCUSSION

The present study aimed at examining how the context of enunciation affects the evaluation of the truth-value of indicative conditionals and its development. First of all, the results concerning conditionals presented in a context that did not specify any alternative value for the antecedent and the consequent (i.e., NN conditionals) replicated the developmental trend constantly observed (Barrouillet et al., 2008; Gauffroy & Barrouillet, 2009, 2011). The responses progressively evolve from a conjunctive, to a defective biconditional and then a defective conditional interpretation, resulting in an age-related increase in *indeterminate* responses, first on $\neg p \ \neg q$ cases and then on $\neg p \ q$ cases. The second main finding is that the context of enunciation can modulate the understanding of conditionals and modify this developmental trend. Indeed, when conditionals are presented in a context that restricts to only one the possible alternative values for both p and q (i.e., NNR conditionals), the defective biconditional interpretation is predominant for people who are able to initiate the fleshing out process. Our hypothesis is that, as with binary terms, the context affects the output of the analytic system. Following Markovits and Barrouillet (2002), we assume that additional models are constructed through fleshing out by searching relevant knowledge in long-term memory. The restricted context would block this memory search as soon as a one to one correspondence is established between the possible values of the antecedent and the consequent (Barrouillet & Lecas, 1998). As a consequence, the developmental changes due to differences in the efficiency of the analytic system are reduced and sometimes abolished. The

hypothesis that restricted contexts mainly affect the fleshing out process is corroborated by the fact that third graders who favoured conjunctive interpretations remained unaffected by this manipulation.

Although we interpret the occurrence of indeterminate responses as resulting from the construction of possibilities through fleshing out, an alternative explanation is proposed by the suppositional theory (Evans & Over, 2004). This theory assumes that people assess conditional through the Ramsey test, focusing on the antecedent possibility and considering $\neg p$ possibilities as irrelevant, something leading to the defective conditional interpretation. Evans and Over (2004) account for the existence of biconditional interpretations by supposing that converse or inverse implicature are added by the heuristic system to the epistemic model ($p \rightarrow q$). Adding converse implicature (if q then p) to “if p then q ” conditionals should lead to defective biconditional interpretations, whereas adding the inverse implicature (if not p then not q) should lead to the equivalence reading. However, concerning NNR conditionals, this supposition is implausible. Indeed, if the explicit mention of alternative values for the antecedent and the consequent triggered an invited inference, this inference would most probably involve these alternative values and consequently take the form of the inverse (if not p then not q) and not of the converse of the initial statement, resulting in an equivalence reading and not the observed defective biconditional interpretation.

Rather, the interpretation of basic conditionals as defective conditionals is a good example of the principle of modulation postulated by the mental model theory according to which the meaning of the antecedent and the consequent as well as knowledge about the context of an assertion can modulate the meaning of sentential connectives like “if” (Johnson-Laird & Byrne, 2002). The effect of the modulation is here to block the representation of a possibility ($\neg p \wedge q$) to which the conditional refers, in the same way as limited cognitive capacities in adolescents often limit their fleshing out process to the $\neg p \wedge \neg q$ model, resulting in the defective biconditional reading observed in developmental studies. Concerning BB conditionals (e.g., “if the light is lit, then the door is open”), semantic modulation would prevent the production of the “off – open” model by strongly associating “off” with “close” in the same way as pragmatic modulation prevents to envision the existence of red Peugeot cars because the context strongly associates Peugeot with the blue colour. In both cases, modulation affects the fleshing out process, resulting in variations in indeterminate responses.

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