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In the beginning stages: Conditional reasoning with category based and causal premises in 8- to 10- year olds

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ABSTRACT

Understanding the development of conditional (if-then) reasoning is critical for theoretical and educational reasons. Previous results have shown that there is a clear qualitative transition between reasoning with true causal conditionals and reasoning with either with contrary-to-fact and fully abstract premises. We examine the further idea that there is a similar developmental transition between reasoning with category-based premises (If an animal is a dog, then it has a tail) and with familiar causal conditionals (If a rock is thrown at a window, then the window will break). A total of 585 students between 8 and 10 years of age received priming conditions designed to encourage use of an alternatives generation strategy and reasoning problems with category based premises and causal premises in a counterbalanced order (with many or few potential alternatives). Results show that reasoning with category based premises is less difficult than reasoning with causal premises, at all ages, and that reasoning first with causal premises causes a global decrease in logical reasoning compared to reasoning first with category based premises. However, no effect of priming was observed. Results support the idea that there is a transition in the reasoning processes in this age range associated with the nature of the alternatives generation process required for logical reasoning with category based and with causal conditionals. However, this transition is less qualitatively extreme than that between reasoning with familiar premises and reasoning with premises that have no empirical basis.

1. Introduction

Conditional reasoning involves making deductive inferences based on an initial if-then premise. Conditionals serve many important functions both in terms of logical reasoning and in terms of the way that people convey different forms of hypothetical relations. Understanding the development of conditional reasoning is thus of critical importance in being able to trace the developmental trajectory underlying logical reasoning. In addition, given the importance of logical reasoning to advanced mathematical and scientific understanding, understanding how conditional reasoning develops has very important educational implications.

Different approaches to conditional reasoning have often led to very different conclusions, reflecting the wide variation in empirical results. On the one hand, some researchers have claimed that conditional reasoning is fully accessible to even very young children, after studies that have shown that in certain cases very young children can indeed give the logically correct responses to conditional inferences (Dias & Harris, 1988, 1990; Hawkins, Pea, Glick & Scribner, 1984). Others have emphasized the fact that even very well educated adults find it very difficult to give consistently correct responses to what

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appeared to be the same problems that young children appear to reason well with (Cummins, Lubart, Alksnis, & Rist, 1991; Evans, Barston & Pollard, 1983), leading them to assume that few people are able to reason logically. Underlying this wide divergence is one basic fact. The inferences that both children and adults make to what are seemingly identical forms of conditional inferences vary dramatically according to the content of the premises. The key to reconciling what appears to be such inconsistent results is understanding how content can affect the developmental processes required to make conditional inferences. The present study focusses on elementary school children's ability to reason with causal and with categorical premises.

Conditional reasoning involves reasoning on the basis of a given "if P then Q" premise (where P is the antecedent term and Q is the consequent term). There are four basic inferences that can be made from a given if-then premise, by affirming or denying the antecedent or the consequent. Two of these lead to logically certain conclusions. The most direct of the four inferences is called Modus ponens (MP), from the Latin term meaning "affirms by affirming" and involves the following premises: "If P then Q, P is true" and leads to the logical conclusion that "Q is true". The Modus tollens (MT) inference, from the Latin term meaning "denies by denying" involves the premises: "If P then Q. Q is false" and leads to the logical conclusion that "P is false". The two remaining inferences do not allow any certain conclusion. The first of these is the Affirmation of the consequent (AC), which involves the premises: "If P then Q. Q is true". Take for example, "If a rock is thrown at a window, then the window will break. Suppose that a window is broken." In this case, the conclusion that "a rock was thrown at the window" is not logically certain since something else might have broken the window. The second of these is the Denial of the antecedent (DA), which involves the premises: "If P then Q. P is false". Similarly to the analysis of the AC inference, the possible conclusion that "Q is false" is not certain.

Empirical results that have examined children's and adults' ability to make logical inferences with conditional premises have shown a mixed pattern of results. Several studies have shown that even quite young children are able to make logically correct inferences (Dias & Harris, 1988, 1990; Hawkins, Pea, Glick & Scribner, 1984). Others have shown clear developmental patterns in children's and adolescents' ability to do so (Barrouillet & Lecas, 1999; Janveau-Brennan & Markovits, 1999; Markovits & Vachon, 1989; O'Brien & Overton, 1980; Overton, Byrnes, & O'Brien, 1985). Finally, many studies have shown that even educated adults have difficulties making logically correct inferences (Cummins, Lubart, Alksnis, & Rist, 1991, Cummins, 1995; Markovits, 1985; Thompson, 1994). Existing developmental theories tend to focus on one or the other of these patterns of results (see Ricco (in press) for a comprehensive review). For example, the competence performance model developed by Overton and colleagues (Overton & Ricco, 2011) focuses on developmental improvements in reasoning while paying some attention to the difficulties that adults may have due to various kinds of performance factors. This model has a Piagetian underpinning and shares with this latter the basic idea that truly logical reasoning does not develop before adolescence. Barrouillet and colleagues (e.g. Barrouillet & Lecas, 1999; Geoffroy & Barrouillet, 2000) have used a mental model analysis that uses the number of models required to instantiate a fully conditional interpretation and the resulting load on working memory to produce a developmental analysis. This model also claims that pre-adolescents are not able to generate a conditional interpretation of conditional statements, using truth-table like tasks (although see Markovits, Brisson & de Chantal, 2016). On the other hand, the metacognitive model proposed by Moshman (2004) focuses more specifically on early ability to make logical inferences, with development seen as due to a basically metacognitive component.

These theories focus on important large-scale variations in reasoning ability, and in many cases they highlight some important, although somewhat contradictory developmental factors. For example, Overton's neo-Piagetian model recognizes that even pre-adolescents are capable of some form of more concrete reasoning, but that this contrasts with the more formal reasoning that is found with more abstract propositional contexts (Byrnes & Overton, 1986). Barrouillet's theory focusses specifically on the working memory constraints required to maintain a conditional interpretation, but suggests that this is not possible before adolescence. However, there are some important factors that are not addressed by these larger-scale theories that are tied to the specific content of the premises used for reasoning. One of the most robust effects that have been observed in the reasoning literature concerns the effects of the relative accessibility of *alternative antecedents* on the ability of children and adults to correctly reject the implied conclusions on the AC and the DA inferences. These are cases of A and Q, where A is not P (e.g. for the premise If a rock is thrown at a window, the window will break, throwing a chair at a window is an alternative antecedent). Many studies have found that when people reason with premises for which they have ready access to more such alternatives, they tend to more often (correctly) deny these two inferences (Cummins et al., 1991; Cummins, 1995; Markovits & Vachon, 1990; Thompson, 1995).

The relative accessibility of alternative antecedents can account for a great deal of the variation in logical reasoning within a given type of premise. For example, this dimension has been used to explain differences in reasoning with causal conditional premises (Cummins et al., 1991; Cummins, 1995; Markovits & Vachon, 1990), with deontic conditionals (Thompson, 1994, 2000), and with category-based conditionals (Markovits, 2000). Importantly, such alternative antecedents must be generated by a reasoner, since they are not part of the information provided by problem premises (we refer to the process by which alternatives are generated as the AGP for brevity). In addition to this form of variation, there is clear evidence that major developmental differences are related to premise type. Developmental results suggest that we can distinguish a sequence of four classes of premise content for which there appears to be consistent age-related differences in logical reasoning. These are respectively, category based premises (if an animal is a dog then it has four legs), causal premises (the rock is thrown at a window, then the window will break), contrary to fact premises (if a feather is thrown at a window, then the window will break) and abstract premises (if X, then Y). There is in fact direct evidence that rates of logical reasoning are lower with contrary to fact premises than with causal premises (Markovits & Vachon, 1989) and that rates of logical reasoning are lower

with abstract premises than with contrary to fact premises (Markovits & Lortie Forgues, 2011). There has however been no study directly comparing the first two, although separate studies suggest that category based premises (Markovits, 2000) produce logical reasoning at an earlier age than do causal premises (Janveau-Brennan & Markovits, 1999). A key related developmental distinction refers to the process by which the process of alternatives generation (which we will refer to as AGP for brevity) functions with these different forms of content (see Markovits, 2014; Markovits & Lortie Forgues, 2011 for details).

Previous results have shown not only differences in rates of logical reasoning between different contents, but suggest two forms of interaction that further characterize developmental differences related to content. First, when reasoning with content A requires a more abstract form of AGP than reasoning with content B, reasoning with both A and B produces lower levels of logical reasoning when A is given first than when B is given first (e.g. Markovits & Lortie-Forgues, 2011; Markovits & Vachon, 1990) Second, when reasoners have difficulty in initiating the processes required for AGP with content that is more abstract than they are used to, their level of logical reasoning can be improved by being given an generation of alternatives task (in which participants are simply asked to generate potential alternatives for a given class of premise). For example, it has been shown that children in the early years of primary school (6 to 7 years of age) will reason better with familiar categorical premises when primed to do so by an alternatives generation task using causal premises (Markovits & Brunet, 2012).

The general aim of this study is to examine early developmental differences in reasoning with category based and causal premises. The basic hypothesis is that reasoning with the latter is more difficult than reasoning with the former. However, there are two further points that are examined here. There is clear evidence that reasoning with both forms of premise use basic memory retrieval processes to generate alternatives (e.g. Markovits, 2000; Quinn & Markovits, 1998). However, there is reason to think that the AGP for category based premises is less abstract than that for causal premises. Generating alternatives for categorical premises of the form "If something is in category P, then it has property Q" requires accessing other categories that share the same property Q (which can be done by identifying other categories with the same property). By contrast, alternatives for causal premises of the form "If cause P, then effect Q" requires generating an ad hoc category of things that can also cause effect Q, a more weakly defined, and thus more abstract, category. If this is the case, then it would be predicted that reasoning with both category based and causal premises would generate globally lower levels of logical reasoning when causal premises are given first (in line with similar order effects cited previously).

The effects of priming reasoning by using a generation of alternatives task initially is also examined here. There is no clear hypothesis. Lack of a priming effect would suggest that while there might be a difference in level of abstraction between category based and causal reasoning, both forms use basically similar and familiar processes. The existence of a priming effect would suggest that the difference between these two forms of reasoning is developmentally more important.

2. Method

2.1. Participants

A total of 585 students participated in this study. Of these, 119 were in primary grade 3 (average age = 8.2 years; range: 7.4 years to 9.0 years; 64 girls, 55 boys), 222 were in primary grade 4 (average age = 9.3 years; range: 8.3 years to 10.1 years; 126 girls, 96 boys), and 244 were in primary grade 5 (average age = 10.3 years; range: 9.5 years to 11.9 years; 135 girls, 109 boys). All students were French speaking and came from middle to lower-middle class neighbourhoods. Ethical approval for this study was obtained from the IRB of Université du Québec à Montréal.

2.2. Material

Booklets were constructed using combinations of the following components. For the reasoning problems, participants first were given the following instructions (translated from the original French).

"In the following exercises, you must consider everything that is written at the top of each page as being always true. You will be given some situations, and you must choose the response that seems logical to you."

Following the instructions, a series of reasoning problems are presented involving some combination of the following premises. Premises were chosen to have either relatively few or many potential alternative antecedents. These were taken from previous studies (Cummins et al., 1991; Markovits, 2000).

2.3. Categorical conditional reasoning problems: few alternatives

On the top of the page following instructions appeared the following:

"Suppose that it is true that:

If a plant is a cactus, then the plant will have thorns.

For each of the following questions, choose the most logical response."

Directly below this, participants were given four inferences each of which had three possible responses. These corresponded to the MP, DA, AC, and MT inferences. The first was presented in the following way:

Table 1
Summary of experimental conditions.

Condition	Premise type for reasoning task	Generation task	Reasoning set 1	Reasoning set 2
Causal priming	Few alternatives	Causal	causal category-based	category-based causal
	Many alternatives	Causal	causal category-based	category-based causal
Categorical priming	Few alternatives	Causal	causal category-based	category-based causal
	Many alternatives	Causal	causal category-based	category-based causal
No-priming	Few alternatives	None	causal category-based	category-based causal
	Many alternatives	None	causal category-based	category-based causal

1. A plant is a cactus
   (a) It is certain that the plant has thorns.
   (b) It is certain that the plant does not have thorns.
   (c) It is not certain whether the plant has thorns or not.

The three other inferential problems used the same format. On the subsequent page, participants were given the major premise "If an object is a knife, then it will have a blade." Four inferential problems corresponding to the MP, DA, AC, and MT inferences were presented directly following the premise.

Category-based conditional reasoning problems: many alternatives. These used the following premises:

If something is a tricycle, then it has wheels.

If an animal is a cat, then it has a tail.

Causal conditional reasoning problems: few alternatives. These used the following premises:

If it rains, then the sidewalk will be wet.

If a person cuts their finger, then their finger will bleed.

Causal conditional reasoning problems: many alternatives. These were identical to the few alternatives problems, with the exception being the specific premises used, which were:

If a rock is thrown against a window, then the window will break.

If a glass is dropped on the ground, then there will be a sound.

Two generation of alternatives tasks were also used in certain conditions. This presented participants with two causal or two category based premises and asked them to simply generate as many alternatives to the antecedent as they were able to. The premises used were designed to allow for many possible alternatives, and were taken from previous studies.

Causal generation task. On the top of the first page appeared the following instructions:

"Read carefully what is written in the following pages and answer the questions."

Following this, participants were given two generation problems. These were as follows:

"If you put ketchup on a sweater, then the sweater will become dirty. Can you imagine other ways to make a sweater dirty? Give as many responses as you can."

"If you throw a rock into a window, then the window will break. Can you imagine other ways to break a window? Give as many responses as you can."

Each problem was followed by 12 double spaced lines.

Category-based alternatives generation task. This was presented identically to the causal generation task, except that the following problems were presented;

"All dogs have legs. Can you imagine other animals that have legs? Give as many responses as you can."

"All cars have a motor. Can you imagine other things that have motors? Give as many respon and ses as you can."

It should be noted that the premises used in the generation tasks differed from those used in the reasoning tasks. Booklets were constructed, in equal numbers, by each of the following combinations of these components, see Table 1. Note that for each premise type, the order of the reasoning problems was alternated.

2.4. Design

The dependent variable is performance on conditional reasoning problems involving the MP, AC, DA, and MT inferences. Each problem set used one major premise and presented all four inferences. Participants received two problem sets using categorical premises and two problem sets using causal premises (thus participants responded to 2 of each of the MP, AC, DA, and MT inferences for each problem type). Problem type (causal or categorical) was a within-subjects variable. Order of presentation of problem types (causal first, categorical first) was systematically varied, and was a between subjects variable. Both causal and categorical premises were chosen to have either Few alternatives or Many alternatives, which was a between subjects variable (Alternatives). Finally, reasoning problems were preceded by either a categorical alternatives

task (category-based priming), a causal alternatives task (causal priming) or nothing (no priming), which was a between subjects variable (Condition).

2.5. Procedure

Booklets were distributed randomly within classes. Students were given verbal directions to read the instructions carefully and to take as much time as they needed to respond to the questions.

3. Results

For each of the 4 logical forms, we calculated the number of logically correct responses (out of a total of 2) as a function of grade level (3, 4, 5), number of alternatives (few, many), condition (causal priming, category-based priming, no priming), and problem order (causal first, category-based first) for categorical and for causal problems. However, simply using scores on individual inferences can be misleading. As we have argued previously (Markovits & Lortie Forgues, 2011), logical reasoning minimally requires being able to (1) accept the premise, which implies accepting the MP inference and (2) at the same time, understand the uncertainty of the AC and DA inferences. Since accepting the premise is such a critical component of "logical" reasoning, it is important to distinguish responses that are attributable to premise rejection, rather than logical reasoning. For example, previous results have suggested that children and adults who do not accept the major premise (which leads to rejection of the MP inference) tend also to reject the AC and DA inferences (which is superficially the logical response). In order to examine this with the present sample, we calculated the number of times that participants rejected the AC and DA inferences (out of a total of 4) and the number of times that they rejected the MP inference (out of a total of 2). The correlation between these two scores was significant at all grade levels (Grade 3: $r(111) = 0.415$, $p < 0.001$, Grade 4: $r(146) = 0.473$, $p < 0.001$, Grade 5: $r(172) = 0.317$, $p < 0.001$. In other words, there is a clear tendency for people who reject the major premise and thus reject the MP inference to also reject the AC and DA inferences. In this case, rejection of the AC and DA inferences cannot be considered to be the result of logical reasoning. It is thus necessary to distinguish rejection of the AC and DA inferences related to the inability to accept the major premise, and rejection of these inferences accompanied by acceptance of the major premise. It is only the latter that meets the full definition of logical reasoning, which implies the ability to both accept the major premise (and thus accept the MP inference) and to respond logically to the other inferences.

In order to account for this, we used a Logical reasoning score derived from previous developmental studies (e.g. Markovits & Lortie Forgues, 2011). For each of the two problem sets with category-based premises, we calculated (1) the number of times that participants accepted the MP inference and rejected the AC inference, and (2) the number of times that participants accepted the MP inference and rejected the DA inference. The logical reasoning score was the sum of these (this varied between 0 and 4). A similar calculation was made for the problem sets with causal premises. It should be noted that performance on the MT inference is not included in this score. This is because this form of inference is the most complex, and previous results have shown that both developmental patterns and relations between cognitive level and MT responses are ambiguous and difficult to interpret. This will thus be analyzed separately.

We then conducted an ANOVA with Logical reasoning score as dependent variable and Problem type (causal, category-based) as repeated measure and Grade level (3, 4, 5), Alternatives (few, many), Condition (causal priming, categorical priming, no priming), and Order (causal first, category-based first) as independent variables. This gave significant main effects of Problem type, $F(1, 533) = 93.03$, $p < 0.001$, *partial eta*$^2 = 0.149$, Grade level, $F(1, 533) = 3.71$, $p = 0.025$, *partial eta*$^2 = 0.014$, Order, $F(1, 533) = 7.33$, $p = 0.007$, *partial eta*$^2 = 0.014$, and Alternatives, $F(1, 533) = 70.99$, $p < 0.001$, *partial eta*$^2 = 0.118$. There was also a significant interaction involving Problem type X Alternatives, $F(1, 533) = 5.53$, $p = 0.019$, *partial eta*$^2 = 0.010$.

Importantly, no effect of Condition was observed. Before interpreting an absence of any such effect, we conducted a power analysis using G*Power v. 3.9.1.2. This indicated that the probability of detecting a small effect in our sample varied between 0.70 and 76 for each of the three grade levels. The corresponding probability of detecting a medium effect varied between 0.86 and 0.94. It is also useful to note that if we combine the samples across all three grade levels, the probability of detecting a small effect is 0.83 and probability of detecting a medium effect is 0.99. In other words, although we must remain prudent about interpreting the absence of the effect in this case, it does seem reasonable to conclude that the priming conditions (either categorical or causal) had relatively little impact on logical reasoning with familiar premises in this age range.

Post hoc analysis of the significant effects used the Tukey test with $p = 0.05$. Analysis of the effect of Grade level indicated that students in Grade 3 had significantly lower combined Logical reasoning scores ($M = 1.60$, 95% CI [1.42, 1.77]) than students in both Grade 4 ($M = 1.90$, 95% CI [1.76, 2.05]) and Grade 5 ($M = 1.99$, 95% CI [1.85, 2.13]), with the difference between the latter two being not significant. Overall, Logical reasoning scores were higher on the category-based reasoning problems ($M = 2.26$, 95% CI [2.14, 2.37]) than on the causal reasoning problems ($M = 1.49$, 95% CI [1.38, 1.59]). The combined Logical reasoning score was higher for problems with many alternatives ($M = 4.47$, 95% CI [4.23, 4.71]) than for problems with few alternatives ($M = 2.91$, 95% CI [2.69, 3.13]), see Fig. 1.

Presenting the category-based reasoning problems first produced a combined Logical reasoning score that was greater ($M = 2.03$, 95% CI [1.91, 2.16]) than that produced when presenting the causal reasoning problems first ($M = 1.74$, 95% CI [1.62, 1.86]), see Fig. 2.

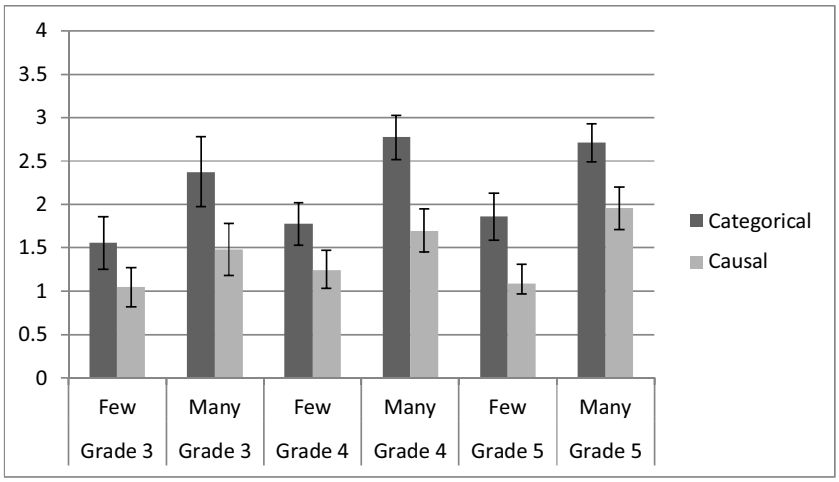

Fig. 1. Mean number of logical responses (out of 4) for categorical and causal premises as a function of Grade level and premise type (few, many).

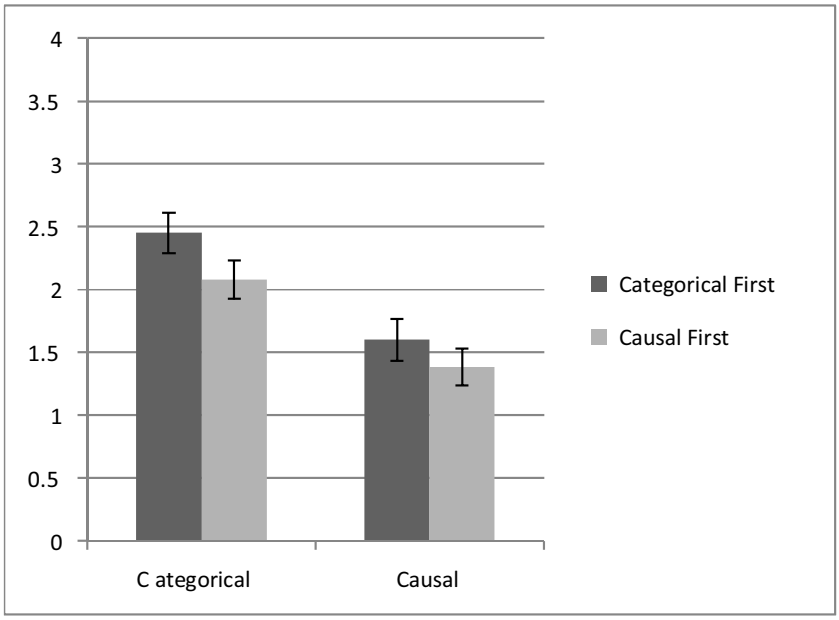

Fig. 2. Mean number of logical responses (out of 4) for Categorical and Causal premises as a function of Order (Categorical first, Causal first).

We then examined the Problem type X Alternatives interaction. Levels of Logical reasoning were greater on the category-based than on the causal premises, both for premises with Few alternatives (categorical: M = 1.74, 95% CI [1.60, 1.91]; causal: M = 1.16, 95% CI [1.01, 1.27]) and for premises with Many alternatives (categorical: M = 2.69, 95% CI [2.52, 2.83]; causal: M = 1.78, 95% CI [1.63, 1.94]), although the relative difference was greater for the latter.

We then examined performance on the generation task. We first examined the numbers of alternatives generated as a function of grade level and of the nature of the task. We started by calculating the total number of alternatives generated on the two generation tasks, for both the causal generation and the category-based generation tasks. We then conducted an ANOVA with Number of alternatives generated as dependent variable and Type (categorical, causal) and Grade level as independent variables. This gave significant main effects of Grade level, $F(2, 349) = 23.64$, $p < 0.001$, *partial eta*$^2 = 0.123$ and of Type, $F(1, 349) = 21.32$, $p < 0.001$, *partial eta*$^2 = 0.058$. Post hoc analyses were performed using Tukey tests with $p = 0.05$. Overall mean numbers of alternatives generated were greater for the categorical task (M = 27.06, SD = 18.72) than for the causal task (M = 18.41, SD = 12.02). Overall mean numbers of alternatives generated were significantly greater for children at grade 5 (M = 27.66, SD = 19.27) than for children at grade 4 (M = 21.73, SD = 13.40), which was in turn greater than for children at grade 3 (M = 13.09, SD = 6.62). We then examined correlations between reasoning and performance on the generation tasks. The correlations between numbers of category-based alternatives and reasoning were not significant for both category-based reasoning problems, $r(172) = 0.01$, p = n.s., and for causal reasoning problems, $r(172) = -0.05$, p = n.s.

Similarly, correlations between numbers of causal alternatives and reasoning were nonsignificant for both category-based reasoning problems, r (180) = 0.07, p = n.s. and for causal reasoning problems, r(180) = 0.10, p = n.s.

Finally, we examined responses to the MT inferences. We conducted an ANOVA with Number of correct responses on the MT inferences (out of 2) as dependent variable and Problem type (causal, category-based) as repeated measure and Grade level (3, 4, 5), Alternatives (few, many), Condition (causal priming, categorical priming, no priming), and Order (causal first, category-based first) as independent variables. This gave significant main effects of Problem Type, $F(1, 533) = 9.52$, $p = 0.002$, *partial eta*$^2 = 0.017$, and Grade level, $F(1, 533) = 3.38$, $p = 0.035$, *partial eta*$^2 = 0.012$. There were also significant interactions involving Problem type X Alternatives, $F(1, 533) = 13.61$, $p < 0.001$, *partial eta*$^2 = 0.025$, and Condition X Order, $F(1, 533) = 3.41$, $p = 0.034$, *partial eta*$^2 = 0.013$.

Post hoc analysis used the Tukey test with p = 05. This showed that there was a significant increase in the combined number of correct responses to MT inferences between grade 3 (M = 1.09, 95% CI [0.92, 1.15]) and grade 4 (M = 1.20, 95% CI [1.12, 1.28]). In addition was a significant decrease in correct responses between grade 4 and grade 5 (M = 1.03, 95% CI [0.97, 1.13]). Analysis of the Problem type X Alternatives interaction indicated that there were for causal premises, there were more correct responses with few alternatives (M = 1.10, 95% CI [1.02, 1.19]) than with many alternatives (M = 0.96, 95% CI [0.87, 1.05]), while for categorical premises, there were more correct responses with many alternatives (M = 1.23, 95% CI [1.15, 1.32]) than with few alternatives (M = 1.10, 95% CI [1.02, 1.19]). Analysis of the Condition X Order interaction indicated that there was a significant effect of condition when causal premises were given first, but not when categorical premises were given first. In the former order, the overall number of correct responses was significantly lower following causal primes (M = 1.91, 95% CI [1.66, 2.15]) than following categorical primes (M = 2.33, 95% CI [2.09, 2.57]) with neither of these being significantly different from performance on the no generation condition (M = 2.22, 95% CI [1.99, 2.43]).

4. Discussion

One of the clearest results of the many studies that have examined conditional reasoning is the strong effect of content on the inferences that both children and adults make to what are formally identical premises (Cummins et al., 1991; Cummins, 1995; Markovits & Vachon, 1990; Thompson, 1995). A key component of this variation is the effect of the relative numbers of alternative antecedents that are suggested by premises on reasoning with the AC and DA forms, an effect that is replicated in the present study. Importantly, there is also evidence that suggests the existence of four types of premise, which might constitute a developmental hierarchy. These are (1) category-based premises, (2) causal premises, (3) contrary to fact premises and (4) abstract premises. Previous studies allow the conclusion that reasoning with contrary-to-fact and abstract premises represent a qualitative transition compared to reasoning with familiar premises (Markovits & Lortie Forgues, 2011; Markovits, 2014). Within this globally more abstract level, these results also show that reasoning with abstract premises is more difficult, and of a higher level of abstraction, than reasoning with contrary-to-fact premises. The results of the present study allow some conclusions that complement this analysis. They show both a presence of a clear developmental increase in logical reasoning between Grade 3 (8-years of age) and Grade 4 (9-years of age) accompanied by a continued strong influence of premise content throughout the entire age range studied here (see Fig. 1). Levels of logical reasoning are clearly greater for categorical reasoning than for reasoning with causal premises. In addition, within each class of premise content, higher levels of logical reasoning are found with premises that have relatively many alternatives than with premises that have relatively few alternatives, consistent with many previous results.

In addition to the overall differences in rates of logical reasoning between categorical and causal premises, these results also show the hypothesized order effect. Specifically, when children reason with both forms of premises, being given problems with causal premises first results in a lower overall level of logical reasoning compared to reasoning first with categorical premises. These results are thus consistent with the idea that reasoning with causal premises is of a somewhat higher level of abstraction than reasoning with categorical premises. However, the lack of any effect of the priming procedure also suggests that both forms of reasoning share a common retrieval-based component. This is reinforced by the strong influence of relative numbers of alternatives on both categorical and causal premises.

In this context, the question of what underlies the order effect is an interesting one. There are several possible explanations. The most direct would suggest that there might be a simple carryover effect, so that logical or non-logical responses produced on an initial set of problems would tend to be transferred to the next set of problems. However, there is evidence that this is not the case, since preceding more difficult problems with easier ones, which have greater levels of logical reasoning has no effect (e.g. Markovits & Lortie Forgues, 2011). This suggests that it is not the actual responses that are responsible for such order effects, but that these effects are due to the way that information is processed. The results showing order effects suggest that causal reasoning is improved by initial categorical reasoning, while categorical reasoning decreases with initial causal reasoning (see Fig. 2). While there is no way of being certain without more empirical data, this pattern suggests that this order effect is explicable by some form of analogical transfer between the AGP for both forms of premise, although this remains speculative.

Finally, it is important to note that the definition of logical reasoning used here required both accepting the MP inference (indicating an ability to accept the major premise) and to reject the AC and DA inferences. This measure does not consider performance on the MT form, since previous results indicate that performance on this form is difficult to interpret. This is reinforced by the analysis of children's MT performance in the present study. First, although there is an increase in correct responding between Grades 3 and 4, there is a corresponding decrease between Grades 4 and 5, mirroring pre-

vious developmental results (e.g. O'Brien & Overton, 1980). Second, the effect of relative numbers of alternatives differs between categorical and causal premises. Interestingly, for the latter, children generally produce fewer correct responses with premises for which there are relatively many alternatives, an effect that has sometimes been found with adults. Both of these results indicate the ambiguity of interpreting MT performance. Although outside of the scope of the present study, it should be noted that a mental model analysis of MT inferences has been used to attempt to understand this pattern of results (Markovits & Doyon, 2004). This suggests that the 'correct' response to MT can be produced by both a simple strategy involving a biconditional interpretation of the conditional or by a more complex strategy requiring inclusion of the possibility of alternative antecedents. In this context, reasoners who give an incorrect response are sometimes using a more advanced form of reasoning than those who give the correct response (see Markovits & Doyon, 2004 for supporting evidence) which would explain the present results and others.

Overall, these results provide an important clarification of the transitional phase between reasoning with familiar categorical and causal premises and the more abstract forms of reasoning involving contrary-to-fact and abstract premises. As mentioned in the introduction, many developmental theories concentrate on larger-scale differences in the way that children reason (e.g. Barrouillet & Lecas, 1999; Overton & Ricco, 2011). The results of this study, along with others (Markovits & Brunet, 2012; Markovits & Lortie-Forgues, 2011; Markovits, 2014) suggest that the ability to reason logically follows a sequence that is not only characterized by an important qualitative step (such as that between concrete and abstract forms of reasoning), as is also suggested by these theories, but that there also exist more fine-grained transitions in reasoning abilities. Thus, despite the fact that both categorical and causal reasoning are examples of concrete, knowledge-based reasoning, the present results show that the latter is developmentally more difficult and of a somewhat higher level of abstraction.

Overall, these results illustrate the importance of considering how content can influence reasoning in a developmental perspective. They suggest that the ability to reason follows a relatively fine-grained developmental pattern that cannot be adequately captured by larger scale analyses. They also suggest that any analysis of the development of reasoning during pre-adolescence (and later) must involve some active information processing component.

Finally, it should be noted that these results have some clear implications for the interpretation of early ability to make logical inferences. The clearest such evidence has been found with some forms of categorical premise (e.g. Markovits, 2000). The present results suggest that this does not indicate the early presence of any general logical competence, but is an indicator of the beginnings of the process of acquisition of the information processing capacity required for reasoning easily with familiar content.

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