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Information processing and reasoning with premises that are empirically false: Interference, working memory, and processing speed

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In this study, we looked at the contributions of individual differences in susceptibility to interference and working memory to logical reasoning with premises that were empirically false (i.e., not necessarily true). A total of 97 university students were given a sentence completion task for which a subset of stimuli was designed to generate inappropriate semantic activation that interfered with the correct response, a measure of working memory capacity, and a series of logical reasoning tasks with premises that were not always true. The results indicate that susceptibility to interference, as measured by the error rate on the relevant subset of the sentence completion task, and working memory independently account for variation in reasoning performance. The participants who made more errors in the relevant portion of the sentence completion task also showed more empirical intrusions in the deductive reasoning task, even when the effects of working memory were partialed out. Working memory capacity was more clearly related to processes involved in generating uncertainty responses to inferences for which there was no certain conclusion. A comparison of the results of this study with studies of children's reasoning suggests that adults are capable of more selective executive processes than are children. An analysis of latency measures on the sentence completion task indicated that high working memory participants who made no errors on the sentence completion task used a strategy that involved slower processing speed, as compared with participants with similar levels of working memory who did make errors. In contrast, low working memory participants who made no errors on the sentence completion task had relatively shorter reaction times than did comparable participants who did make errors.

Logical reasoning involves making deductions on the basis of some given premises that are considered to be true. Although there have been a great many studies of how both children and adults reason, one of the most important characteristics of such reasoning has been relatively neglected. Specifically, the ability to reason "logically" with premises that are not necessarily true (Inhelder & Piaget, 1958) is a vital component of advanced reasoning. This basic ability underlies much of modern science, where disregarding what is "believable" in order to follow a train of thinking to a logical (and often, startlingly unbelievable) conclusion is a key element. However, research has consistently shown that even educated adults have difficulties in reasoning "logically" with false premises (e.g., George, 1995, 1997; Markovits & Potvin, 2001; Markovits & Vachon, 1989). Understanding the processes involved in such reasoning is thus particularly important. In the following, we examine the relation between some key information-processing variables (executive control, working memory [WM], and processing speed) and individual differences in logical reasoning with conditional (if–then) premises that are not necessarily true.

Conditional reasoning in its most basic sense involves making inferences with a given major premise of the form "P implies Q" and one of four possible minor premises. Modus ponens (MP) is the logical principle that involves reasoning with the premises "P implies Q, P is true" and leads to the logically correct conclusion "Q is true." Modus tollens (MT) involves reasoning with the premises "P implies Q, Q is false" and leads to the logically correct conclusion "P is false." These two are valid logical forms, since they both lead to a single, logically correct conclusion. Affirmation of the consequent (AC) involves reasoning with the premises "P implies Q, Q is true." Denial of the antecedent (DA) involves reasoning with the premises "P implies Q, P is false." In both cases, the implied conclusions, "P is true" for AC and "Q is false" for DA, are not logically correct. Neither of these forms leads to a single, logically correct conclusion, and the correct response would be to deny the implied (biconditional) conclusion in both cases and give a response of uncertainty.

Conditional Reasoning and Information Retrieval

One of the more striking results of studies of conditional reasoning with concrete premises is the very large

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effect of premise content on the kinds of inferences that are made (e.g., Cummins, 1995; Cummins, Lubart, Alksnis, & Rist, 1991; Janveau-Brennan & Markovits, 1999; Markovits & Vachon, 1989; Thompson, 1994). These studies suggest that one key process in the way that inferences are made involves active retrieval of information about the premises from long-term memory (Cummins, 1995; DeNeys, Schaeken, & d'Ydewalle, 2002; Markovits & Barrouillet, 2002; Markovits, Fleury, Quinn, & Venet, 1998; Oaksford, Chater, & Larkin, 2000).

This research has shown the presence of two important classes of information: alternative antecedents and disabling conditions. Consider the conditional premise "if a rock is thrown at a window, the window will break." An alternative antecedent refers to the possibility of attaining the consequent in a way that is different from that employing the antecedent. In this case, an example of an alternative antecedent is "throwing a chair at the window." A disabling condition is such that, when in conjunction with the antecedent, it allows the latter to be true while the consequent may not be true. In the present case, "the window is made of Plexiglas" is an example of a disabling condition. Existing research has shown that retrieval of information about potential alternative antecedents is strongly related to inferences made on the AC and DA forms (Cummins, 1995; Cummins et al., 1991; Markovits & Vachon, 1989). Greater availability of disabling conditions is associated with decreased acceptance of the MP (and MT) inference (Cummins, 1995; Cummins et al., 1991; De Neys et al., 2002; Janveau-Brennan & Markovits, 1999; Vadeboncoeur & Markovits, 1999). Thus, when premises allow ready access to information that the major (if–then) premise is false (i.e., that in some real-life cases, P can be true without Q necessarily being true), such retrieval processes would result in reasoning that reflects this stored knowledge and should lead to a tendency to deny the MP and MT inferences.

There is, in fact, a great deal of evidence that this is often the case, both with children (Dias & Harris, 1988, 1990; Markovits & Vachon, 1989) and with adults (Cummins, 1995; George, 1995, 1997; Markovits & Potvin, 2001; Thompson, 1994). However, it is also true that children and adults can use logical instructions to "suppose that these premises are necessarily true" to limit the tendency to make empirically plausible inferences that are inconsistent with these instructions (Markovits & Vachon, 1989; Vadeboncoeur & Markovits, 1999).

Reasoning and Executive Processes

Evidence of this kind has led Markovits and colleagues to suggest that the effect of typical instructions to "suppose that the premises are true" on reasoning with premises for which a reasoner has ready access to information that puts into doubt the necessary truth of the premises is to promote inhibition of the latter kind of information (Markovits & Barrouillet, 2002; Markovits et al., 1996; Simoneau & Markovits, 2003). There are two sources of evidence that are consistent with this idea. First, recent studies with children have shown that individual differences in performance on measures of inhibition are related to the tendency to make "logical" inferences on simple conditional reasoning problems with unbelievable premises (Handley, Capon, Beveridge, Dennis, & Evans, 2004; Simoneau & Markovits, 2003). Second, studies with adults have shown that activating information retrieval processes after logical instructions increases the tendency to make empirically appropriate, but logically inappropriate, inferences (Markovits & Potvin, 2001; Vadeboncoeur & Markovits, 1999). It must also be noted that inhibitory processes have been implicated in the potentially related capacity to avoid making heuristic judgments on such problems as the selection task (Houdé et al., 2000) and a probability judgment task (Moutier & Houdé, 2003).

At this point, it is useful to briefly note that there is some dispute about the exact nature of the processes that underlie many common measures of inhibition (see Tipper, 2001, for a recent review). It is, for example, difficult to distinguish between inhibition of competing activation or retrieval and interference effects (e.g., Neil, 1997; Neil & Valdes, 1992). The model that we present relies on the general claim that the executive control processes that enable reduction of the potential effects of activation of inappropriate information, whether this involves inhibition or resistance to interference, are also implicated in reasoning with false premises. We will refer to this dimension as *susceptibility to interference*. Thus, failure to reason with premises "as if they were true" would be due to a failure to control the inappropriate activation of information that suggests that the premises are not, in fact, necessarily true. The first aim of the present study was to examine whether the relationship between individual differences in susceptibility to interference and the ability to make conditional inferences with premises that are not necessarily true in real life is present in adult reasoners. In addition to this, we wished to examine a more specific prediction. Simoneau and Markovits (2003) found that individual differences in susceptibility to interference (on a negative-priming task) were related to both a decrease in nonlogical inferences on the MP and MT forms and a decrease in the proportion of logically correct (uncertainty) responses to the AC and DA forms. These results, along with others pertaining to the effects of embedding false premises in fantasy contexts (Markovits, 1995; Markovits et al., 1996) indicate that such control processes in children appear to be relatively undifferentiated. Specifically, this evidence strongly suggests that when children are asked to reason with false premises under logical instructions, they will globally reduce use of empirical information about the premises in the reasoning process. This results in an increased tendency to respond "logically" to the MP and MT forms but also generates a corresponding decrease in "logically" appropriate uncertainty responses to the AC and DA forms.

At this point, it might be worthwhile to employ a specific illustration. Suppose that the generally unbelievable premise "if a feather is thrown at a window, then the win-

dow will break" is given, accompanied by standard logical instructions. The analysis that we have used suggests that when the MP inference "if a feather is thrown at a window, will the window break?" is made, if a reasoner can eliminate interference due to the potential activation of information that feathers do not generally break windows, they will be able to respond with the logically correct inference "the window will break." If they cannot do this, then they will respond that "the window will not break" or with a response of uncertainty. On the other hand, consider the AC inference "if a window is broken, was a feather thrown at it?" In this case, responding with uncertainty, which is the "logically" correct response, would require accessing information about other ways of breaking windows (e.g., throwing a stone, etc.). Reasoners who are not able to access this kind of information will tend to respond to the AC inference with a *biconditional* response—that is, they will tend to conclude "that a feather was thrown." The results of Simoneau and Markovits (2003) and others (e.g., Markovits, 1995) indicate that reducing the use of information that feathers do not break windows tends to be accompanied by a reduction in the use of information about other ways of breaking windows in both children and adolescents. Specifically, logical instructions with younger reasoners increase the proportion of logically correct responding to the MP (and MT) forms and also increase the proportion of biconditional responses to the AC and DA forms.

However, developmental data suggest that older reasoners should be more selective about the way that they can control use of information about premises. It has been found that older adolescents generally accept the MP and MT inferences at a higher rate than do younger ones and that this is accompanied by a higher frequency of uncertainty responses to the AC and DA inferences (Markovits, 1995; Markovits & Vachon, 1989). Although this evidence remains indirect, it suggests that older reasoners are increasingly able to control interference from information concerning potential disabling conditions in order to accept the MP and MT inferences and that this does not affect their capacity to retrieve and use information about alternative antecedents. We thus predict that individual differences in susceptibility to interference should be related to relative changes in nonlogical inferences on the MP and MT forms but should be unrelated to the proportion of correct uncertainty responses on the AC and DA forms.

A second prediction concerns the interactions between reasoning and WM capacity. WM is generally considered to limit reasoning performance by providing constraints as to the complexity of the components that can be manipulated during reasoning. There is evidence for a general link between WM capacity and deductive reasoning performance (e.g., Kyllonen & Christal, 1990). In the specific case of conditional (if–then) reasoning, there is also evidence that performance on conditional inference tasks is related to WM capacity (Barrouillet & Lecas, 1999; Markovits, Doyon, & Simoneau, 2002; Toms, Morris, & Ward, 1993). There is a relation between WM capacity and the production of uncertainty responses to the AC and DA forms (Barrouillet & Lecas, 1999; Markovits et al., 2002). In fact, there is evidence that this correlation may be due to the relation between WM capacity and the ability to retrieve information about potential alternative antecedents from long-term memory (Markovits & Quinn, 2002). We would thus predict that there would be a positive correlation between WM capacity and production of uncertainty responses to the AC and DA forms.

This brings up the question of what the expected relation should be between WM capacity and inhibition in the context of conditional reasoning. The specific notion of WM that we use here is taken from Kane and Engle (2002), who claimed that "information maintenance in the presence of interference" (p. 639) is the critical dimension of WM capacity. There is clearly an inhibitory component to this definition, and to some extent, there should be a positive relationship between the ability to prevent irrelevant information from intruding into information that is actively being manipulated and the quantity of information that can be actively manipulated despite interference (e.g., Long & Prat, 2002). Generally, it would be predicted that higher WM capacity would correlate with greater capacity to inhibit interference from irrelevant stimuli. However, there is evidence that WM is a better predictor of susceptibility to interference, as measured by the Stroop task, when the irrelevant stimuli are infrequent, but not otherwise, and in addition, that high WM span individuals appear capable of strategically modifying their performance in order to minimize potential interference effects, at least when these are explicitly presented (Long & Prat, 2002). In the case of conditional reasoning, the instructions are given at the beginning of the task, and the same premises are used; thus, the necessity to inhibit potential disabling conditions remains fairly constant. We would thus expect that individual differences in susceptibility to interference from this kind of irrelevant information should have an effect on reasoning independently of WM capacity. Following Long and Prat, we will also examine whether there is any evidence that high-WM individuals are able to employ a strategy designed to reduce the effects of interference in the task that we employ here.

Thus, when we examine the interactions between WM capacity, inhibition, and reasoning with false premises, we would predict that there should be some interaction between WM and susceptibility to interference but that the relation between the ability to accept the MP and MT inferences should be strongly related to inhibitory differences, whereas the ability to produce uncertain conclusions to the AC and DA inferences should be clearly related to WM capacity. Finally, given previous results, we might expect that high WM capacity individuals would show differences in strategies designed to minimize potential interference effects.

There are some methodological considerations that must be mentioned at this point. The first concerns which forms will be used to measure failure to reason "as if the major premise was true." In order to examine this, we con-

centrate on the MP and MT forms. These forms have been shown to be particularly sensitive to information that suggests the presence of disabling conditions (Cummins et al., 1991). This also allows use of uncertainty responses on the AC and DA forms as a separate measure of reasoning, without confounding the two. The second concerns the specific inferences that can be considered to unambiguously mirror inappropriate inclusion of the information that P does not necessarily lead to Q with the MP and MT forms. For each of the logical forms, there are three potential responses, corresponding to the direct inference, the negation of the direct inference, and an uncertainty response. For example, for the MP inference "If P then Q, P is true," the direct inference is "Q is true," and the negation inference is "Q is false." An uncertainty response corresponds to "Q can be either true or false." In the case of the MP form ("P is true"), the direct inference ("Q is true") is the only response that is consistent with accepting the premises. Thus, either "Q is false" or a response of uncertainty indicates inappropriate use of knowledge that the premises are not necessarily true. When reasoning with believable premises, very few such inferences are produced on the MP form. In the case of the MT inference ("Q is false"), the inference that "P is true" clearly corresponds to using inappropriate knowledge. However, an uncertainty response is commonly produced to the MT form with believable premises, and its interpretation is thus ambiguous in this context. For the sake of completeness, it should be noted that negation of the direct inference is a reliable indicator of use of inappropriate knowledge on the AC form, but not on the DA form (see Markovits & Vachon, 1989).

The second point concerns the measure of interference that we used. Previous studies in which conditional reasoning was looked at have used two kinds of measures. The task that was used by Simoneau and Markovits (2003) was Tipper's negative-priming task (e.g., Tipper, 1985), which involves low-level processing, with the interference component completely unknown to the subjects. The stop signal task (Handley et al., 2004) uses explicit instructions to prevent processing of inappropriate stimuli, as does the Stroop task in its various incarnations (e.g., Long & Prat, 2002). These kinds of tasks bracket the nature of the processing that we suppose to be required in conditional reasoning with false premises. Usual instructions to reason logically do not explicitly indicate the necessity of inhibiting information (although see Vadeboncoeur & Markovits, 1999, for an example of more complex instructions), so that use of explicit executive processes is not necessarily in play but may be selectively deployed by individual subjects. At the same time, the kinds of information retrieval processes that are in play in reasoning are more complex than those involved in the negative-priming task.

In addition to these considerations, performance on tasks such as the Stroop is vulnerable to effects of context that can generate variable levels of information processing (e.g., Dulaney & Rogers, 1994; Long & Prat, 2002). A similar effect has been found on Tipper's negative-priming task (Simoneau & Markovits, 2003). We thus wanted a task that (1) required suppression of interference, without using explicit instructions to do so, (2) involved a reasonably high level of semantic activation, and (3) would not be vulnerable to the use of a strategy that affected the level at which information was processed.

We devised a new kind of task to correspond with these characteristics. This task relies on the same basic mechanism as the Hayling test, which has been used as a measure of inhibition in patients with cerebral lesions (Burgess & Shallice, 1996). In the latter task, subjects are explicitly requested to complete a sentence with a response that is not one that would be usually produced. Thus, the suppression of the interference component involves being able to produce a response that differs from one that would be normally produced in response to an incomplete sentence. We constructed a task that similarly required suppression of a strongly associated response to an incomplete sentence but did not use explicit instructions to do so. This task involves presenting an incomplete sentence ("____ is a sport") for a period of 2 sec. The sentence then disappears for 1 sec and is followed by a set of letters. The letters are either words or nonwords and, in the case of words, can either semantically fit into the incomplete sentence or not. The subject's task is to indicate whether or not the presented stimuli fit well into the sentence. The critical element here involves the presentation of nonwords that are very similar to words that are highly associated with the given sentence (e.g., "footbalf"). Errors of identification for this kind of stimulus can be attributed to the influence of the semantic activation due to the incomplete sentence and the physical similarity of the presented nonword to a highly associated word; that is, the more susceptible a subject is to interference from words that are similar to that presented, the greater the chance of making an error in identification. This task does not present explicit requirements for inhibiting information. It involves processing information at a level similar to that used in simple reasoning. Finally, although it is not possible to eliminate use of a low-level processing strategy, this task encourages semantic processing and allows detection of subjects who do not do so (this will be looked at in more detail during the analysis of the results of this task).

Finally, the reasoning tasks that we used were clearly defined as logical tasks. The subjects were given very direct instructions for the logical task that placed a clear emphasis on the requirement to suppose that premises were true, irrespective of whether this was actually so in real life. All the problems involved causal conditionals, since these generally show more variability in performance than do class-based conditionals (Markovits et al., 1998). We also used three different kinds of content for which the kinds of responses that we were looking for are known to be produced. The first were conditionals, which were chosen to allow ready access to empirical information to the effect that P could be true while Q remained false (disabling conditions; Cummins et al., 1991). The second were similar kinds of conditionals, but these were followed by

an explicit request to generate an alternative antecedent, a procedure that has been shown to promote production of conclusions to the MP and MT forms that are empirically plausible but logically inappropriate (Markovits & Potvin, 2001). The third were premises that contradicted otherwise quite believable conditional rules (e.g., "if a dog has fleas, then the dog will not scratch"). Note that previous studies have shown that explicit logical instructions generally lead to very low levels of inappropriate responses to the MP and MT forms (Markovits & Vachon, 1989; Vadeboncoeur & Markovits, 1999). Thus, we would expect a generally low level of these kinds of responses.

METHOD

Subjects

A total of 97 subjects were examined. All the subjects were native French speakers at the same university (average age, 26 years 5 months; 65 females, 32 males). All the subjects were enrolled in a lottery for three cash prizes of $250, $100, and $100.

Materials

Reasoning. A 10-page booklet was prepared. On the first page was space for the subject's age and sex, followed by general instructions. These were (translated from the original French) the following:

> In the following pages, you will have to respond to several logical problems. For each problem, you will be presented with a rule that you must consider to be true. In a logical reasoning task, these rules must be considered to be true, even if this is not always the case in the everyday world. It is very important, in order to respond to the questions that are asked, to suppose that the rule presented on the top of the page is *always true*.

Each of the following nine pages had the same basic format. At the top was the statement "Suppose that it is always true that," followed by an if–then conditional statement. After this, a set of four inferences presented an affirmation or negation of either the antecedent or the consequent term, followed by three possible responses, which took the following general form (this example uses the conditional rule *If gas is put into a car, the car will run*).

> If a car is running, then it can be concluded that:
>
> (1) It is certain that gas has been put into the car.
>
> (2) It is certain that gas has not been put into the car.
>
> (3) It is not certain whether gas has been put into the car or not.

The order of the four inferential problems was varied for each of the nine conditional rules.

The inferential rules used were the following, in the order presented:

> If gas is put into a car, then the car will run.
>
> If a window is hit by a pebble, then the window will break.*
>
> If a dog has fleas, then the dog will never scratch itself.
>
> If Alain is outside in a storm, then Alain will be wet.
>
> If there is a snow storm, then Jean will be late for his meeting.*
>
> If Marie does not plug in her tv, then she will be able to watch her favorite program.
>
> If Chantal exercises, then she will be tired.
>
> If Paul reads the newspaper, then he will be bad tempered.*
>
> If Serge doesn't have an allergic reaction, then he will sneeze.

For the items marked by an asterisk, the conditional premise was followed by instructions to generate another potential antecedent (e.g., another reason for Paul to be bad tempered), before presentation of the four inferential problems. These rules were divided into three sets of three problem types (in the same order). The first problem was a conditional for which pretesting had shown that adults were able to think of many potential ways for the antecedent to be true with the consequent being false (disabling conditions). The second was a problem with many potential disabling conditions with explicit production of an alternative antecedent. The third problem was a premise that was directly contrary to a commonly accepted relation.

WM span. The method used here was Baddeley, Logie, Nimmo-Smith, and Brereton's (1985) adaptation of the measure developed by Daneman and Carpenter (1980) for group testing. This measure is one of a family of WM span tasks that are considered to be valid measures of the WM capacity construct (Kane & Engle, 2002) and has been previously shown to correlate with conditional reasoning performance (Markovits et al., 2002).

A series of short sentences was prepared on audiotape and was played back via an amplifier and speakers. Each of the sentences involved a person, a verb, and an object. The subjects were presented with a sequence of either three or four sentences and were then cued to recall either the person or the object described in each of the sentences. Half of the sentences made sense; the other half did not. In order to ensure comprehension, the subjects were asked to rate each sentence as making sense or not, immediately after presentation, on a score sheet. The test involved four sequences of two sentences (which were used for training and were not scored) and four sequences of three sentences, followed by four sequences of four sentences. The total number of items recalled in correct serial order for the sequences with three and four sentences was then calculated.

Interference measure. A total of 30 incomplete sentences with a missing noun were constructed. Four types of stimuli were associated to each of these sentences. Of these, one was a word whose meaning was consistent with the rest of the sentence, one was a word whose meaning was inconsistent with the rest of the sentence, one was a nonword that was very similar to a word with a meaning that was highly consistent with the rest of the sentence (but differed from the first stimulus), and one was a nonword with no similarity to any word. This gave a total of 120 combinations. These were placed into a single randomly generated sequence consisting of twelve 10-item blocks, with the single constraint that no single block could contain the same sentence twice. Task instructions were presented on a computer screen. These explained the way the task worked with three specific examples for which the subjects would give the appropriate answer, with feedback in case of error. After these instructions, the subjects were asked to proceed as quickly as possible and were given the first two blocks as trial blocks. After each block of trials, the subjects were asked to indicate when they were ready to do the following block by clicking on the computer screen.

For each trial, the base incomplete sentence was shown on the computer screen directly in front of the subject for a period of 2 sec. Following this, the screen was blanked out for 1 sec. After this, the stimulus to be judged was presented on the screen in the middle of the area used to present the sentence. The computer recorded both the response and the response latency, measured from the beginning of the presentation of the stimulus.

Procedure

The subjects were seen individually for periods of around 50 min. The order of presentation of the three tasks was systematically varied between subjects.

RESULTS

We first calculated reliability measures for the WM span task by calculating a Chronbach's alpha for the eight scores; this gave a result of .65. For the related nonword task performance on the sentence completion task, we computed a split-half correlation. This gave a result of .78.

We then specifically examined performance on the sentence completion task that was used as a measure of susceptibility to interference. Recall that the subjects in this task were given four basic forms of problem. For a given incomplete sentence (e.g., "___ is a sport"), these involve presenting a related nonword ("footbalf"), an unrelated nonword ("primg"), a related word ("golf"), and a nonrelated word ("banana"). Our analysis involves the claim that performance on the related nonword problems would require suppression of interference, due to the semantic context activated by both the original incomplete sentence and the physical similarity of the nonword to a word associated with this context. In problems in which words are presented, the semantic context is, in fact, necessary to make an appropriate judgment.

One possibility, however, is for the subjects to adopt a low-level processing strategy that would involve ignoring the initially presented incomplete sentence, thus allowing the subjects to easily identify nonwords without the presence of potential activation of a semantic context. However, although use of this strategy would make nonword judgments relatively easy, it would create real difficulties on problems for which words were presented, since it would be necessary to guess in these cases. In order to account for this possibility, we looked at performance on the 50 problems in which words were given as potential completions. The probability of making 40 or more correct decisions out of 50, using a strategy that requires guessing, is less than .0001. Two subjects made fewer than this number of correct decisions on these problems and were consequently eliminated from the following analyses. We additionally eliminated 1 subject whose error score on the MP and MT problems was more than three standard deviations above the mean. The remaining 94 subjects could thus be assumed to have consistently activated the semantic context described by the incomplete sentence, as shown by their performance on the word problems. The rate of correct identifications of related nonwords will be used as a measure of susceptibility to interference. In this case, fewer correct identifications indicate greater susceptibility.

We then calculated the means and standard deviations for the three tasks. For the reasoning task, we calculated the proportion of logically inappropriate responses that unambiguously indicated use of knowledge that the major premise is not necessarily true for the MP and the MT forms combined. As was stated previously, an inappropriate response on the MP form ("P is true") was either negation of the direct inference ("Q is false") or an uncertainty response. For the MT form ("Q is false"), only negation of the direct inference ("P is true") was considered to be an inappropriate response. We also calculated the proportion of uncertainty responses on the AC and the DA forms combined. For the interference task, we present the mean number and standard deviation of numbers of correct responses for each of the four stimulus types. These are summarized in Table 1. As can be seen from these values, there were relatively few inappropriate errors on the MP and MT forms and also relatively few errors in the word identification task, as would be expected.

Table 1
Means and Standard Deviations for Performance on the Reasoning Task, the Interference Task, and the Working Memory Measure

Measure	*M*	*SD*
Working memory span	17.47	3.24
Correct judgments on related nonwords ($n = 25$)	23.87	1.69
Correct judgments on unrelated nonwords ($n = 25$)	24.87	0.47
Correct judgments on related words ($n = 25$)	22.99	1.56
Correct judgments on unrelated words ($n = 25$)	24.24	1.00
MP and MT inappropriate responses ($n = 18$)	1.96	1.50
AC and DA uncertainty responses ($n = 18$)	11.03	4.12

We then looked at the relation between reasoning performance, WM, and susceptibility to interference. Specifically, we examined the relation between WM span, the number of correct responses to the related nonword condition (which we will subsequently refer to as *inhibitory control*), the total number of inappropriate responses on the MP and the MT forms combined, and the number of uncertainty responses on the AC and the DA forms combined. Since these measures were not normally distributed (particularly in the case of the measure of susceptibility to interference and errors on the MP and MT forms), we used the Kendall tau as a measure of correlation. It should be noted that, in this case, the absolute values were not directly comparable to other measures of correlation. The pattern of correlations is summarized in Table 2. There were, as was expected, significant correlations among most of the variables, with the exceptions being the correlation between inhibitory control and production of uncertainty responses to the AC and DA forms, which was not significant, and that between inhibitory control and WM, which was marginally significant.

The first specific question that we looked at was the relation between susceptibility to interference, production of inappropriate responses to the MP and MT forms, and production of uncertainty responses to the AC and DA forms. There was a clear relation between susceptibility to interference and responses to the MP and MT forms. This indicates that the participants who made fewer errors on the related nonword problem produced fewer inappropriate responses to the reasoning problems. This mirrors previous results with children (Simoneau & Markovits, 2003). The relation between susceptibility to interference and production of uncertainty responses was not significant, in contrast to what has been observed with children. There was also a strong tendency for subjects who produce more uncertainty responses on the AC and DA forms to make fewer inappropriate responses to the MP and MT forms.

We then looked at the specific contribution of susceptibility to interference and WM to both production of inappropriate responses to the MP and MT forms and production of uncertainty responses to the AC and DA forms. The partial correlation between susceptibility to interference and the number of inappropriate responses to the MP and MT forms, with WM partialed out, was .192 ($p < .05$). The partial correlation between WM and the number

Table 2
Correlations Between Working Memory Span, Susceptibility to Interference, the Number of Inappropriate Responses on MP and MT Combined, and the Number of Uncertainty Responses on AC and DA

	Susceptibility to Interference	Inappropriate Responses MP + MT	Uncertainty Responses AC + DA
Working memory	.155*	−.161**	.237***
Susceptibility to interference		−.207**	.117
Inappropriate responses MP + MT			−.345***

*$p < .10$. **$p < .05$. ***$p < .01$.

of inappropriate responses to the MP and MT forms, with susceptibility to interference partialed out, was .138 (p = n.s.). These results indicate that there was a clear relation between susceptibility to interference and production of inappropriate responses to the MP and MT forms, even when the contribution of WM was factored out.

The partial correlation between WM and the number of uncertainty responses to the AC and DA forms, with susceptibility to interference partialed out, was .227 ($p < .01$). The partial correlation between susceptibility to interference and the number of uncertainty responses to the AC and DA forms, with WM partialed out, was .087 (p = n.s.). Thus, there was a very clear relationship between WM and the production of uncertainty responses on the AC and DA inferences, one that was unaffected by susceptibility to interference.

One final point that we examine in this context concerns the question of whether there is any evidence of strategic control in the sentence completion task. In order to do this, we looked at the way that average reaction times in the sentence completion task were related to WM and susceptibility to interference. We performed a stepwise regression analysis, with the mean reaction time on the sentence completion task as a dependent variable, that included WM capacity, susceptibility to interference, and a WM × susceptibility to interference interaction. The resulting model included WM and the WM × susceptibility to interference interaction and accounted for 31% of the variance. The best single predictor was WM, which contributed 20% of the explained variance [$F(2,93) = 13.03, p < .001$], whereas the WM × susceptibility to interference term accounted for an additional 11% of the variance [$F(1,93) = 11.23, p < .01$].

In order to give a synthetic view of what these results mean, we divided up the subjects into three roughly equal groups according to their relative WM capacity. Group 1 comprised individuals whose WM scores were greater than 19. Group 2 comprised individuals with scores varying between 16 and 19, whereas Group 3 had scores less than 16. We then divided the subjects into two further groups: those who made no errors in the related nonword sentence completion task (low susceptibility) and those who made at least one such error (high susceptibility). Table 3 gives the mean reaction times on the sentence completion task as a function of WM and susceptibility to interference. These results show that there is a general increase in reaction times as WM spans decrease (average mean latencies for the four groups are .96, 1.07, and 1.31 for Groups 1–3, respectively). However, the interaction with level of susceptibility to interference shows a variable pattern. For the subjects with low WM spans, reaction times were greater for those who made errors in the related nonword condition, whereas the opposite pattern was observed for the subjects with high WM spans. This is consistent with the idea that a subsection of the high WM span subjects adopted the strategy to slow down their decision-making processes in order to reduce the effects of interference.

DISCUSSION

On-line retrieval of information about premises has been shown to be an important factor in understanding the strong tendency of both children (e.g., Janveau-Brennan & Markovits, 1999) and adults (e.g., Cummins, 1995; Markovits & Potvin, 2001) to make conditional inferences that are empirically plausible. However, any such mechanism cannot explain how reasoners can use logical instructions to make logically appropriate inferences that do not reflect stored knowledge about premises. The results of the present study provide additional general support for the idea that suppression of interference due to activation of inappropriate information (i.e., information that puts the necessity of the premises into doubt) is an important component of logical conditional reasoning with concrete premises. They add to previous results obtained with children that show a relation between individual differences in susceptibility to interference and the ability to reason with premises "as if they were true" (Handley et al., 2004; Simoneau & Markovits, 2003) and to results from other par-

Table 3
Mean Latencies (in Seconds) for Judgments on the Sentence Completion Task for Subjects Classed According to Working Memory Span and as High or Low Susceptibility to Interference

Working Memory	Susceptibility to Interference	n	Mean Latency
>19	Low	15	1.07
	High	13	0.84
16–19	Low	20	1.05
	High	23	1.11
<16	Low	11	1.09
	High	14	1.50

adigms that are consistent with the use of an inhibitory mechanism in other forms of logical reasoning (Houdé et al., 2000; Moutier & Houdé, 2003).

Particularly useful is the contrast with the pattern of results obtained with children. In this context, it should be noted that many accounts of the role of control processes in reasoning assume that these are required to reduce access to nonlogical strategies that may be automatically activated and that interfere with "logical" reasoning. This is common to existing dual-process theories (e.g., Evans & Over, 1996; Sloman, 1996). This basic notion is also consistent with results with inhibition training (e.g., Moutier & Houdé, 2003) that show increases in "logical" responding when children and adults are trained to inhibit use of readily available heuristics. Although this analysis is certainly a reasonable interpretation of available data, the present results provide a more nuanced view of the contribution of control processes to reasoning. Examination of children's conditional reasoning with false premises has generally shown a negative association between responding "logically" to the MP and MT forms and producing "logical" uncertainty responses to the AC and DA forms (e.g., Janveau-Brennan & Markovits, 1999; Markovits, 1995; Markovits & Vachon, 1989; Simoneau & Markovits, 2003). This basic effect is mirrored by the fact that children who have less susceptibility to interference produce fewer empirically valid but logically inappropriate responses to the MP and MT inferences and also produce fewer logically valid uncertainty responses to the AC and DA inferences. Such results are not easily explicable by dual-process theories, since manipulations that increase "logical" responding to the MP and MT forms simultaneously decrease "logical" responding to the AC and DA forms. There is also evidence that children who are more efficient in retrieving alternative antecedents are also more likely to retrieve potential disabling conditions (Janveau-Brennan & Markovits, 1999). Thus, a straightforward interpretation of this pattern of results is that standard instructions (or contextual help) to accept premises as true involve a decrease in use of information about the premises that concerns not only potential disabling conditions, but also alternative antecedents. These results thus indicate that children have a relatively global way of controlling potential interference, at least in the specific case of conditional reasoning with false premises. In contrast, the results of the present study show a clear relationship between susceptibility to interference and production of inappropriate responses to the MP and MT forms, but no relationship between susceptibility to interference and production of uncertain responses to the AC and DA forms. This was mirrored by a strong negative relationship between these two response types, so that subjects producing more "logical" responses to the MP and MT inferences also produced more "logical" responses to the AC and DA inferences. This strongly suggests that, in contrast to children, the control processes of educated adults are specifically targeted toward information that puts into doubt the truth of the major premise but does not affect retrieval of information about alternative antecedents.

Recent developmental analyses treat general inhibitory processes as an important component of cognitive development, one that mirrors the increased efficiency of information retrieval (e.g., Bjorklund & Harnishfeger, 1990, 1995; Demetriou, Christou, Spanoudis, & Platsidou, 2002). Inhibition and control of interference is considered to be a necessary component in managing the increased information load implied by increasing efficiency of retrieval. The present results, in turn, suggest that development is guided not only by a general increase in inhibitory capacity, but also by an increase in the selectiveness of control mechanisms, in situations in which this is required by task constraints.

The results of this study also allow some more specific descriptions of the interaction between susceptibility to interference, WM, and conditional reasoning. There is a (marginally significant) relationship between the measures of WM capacity and susceptibility to interference used here, as would indeed be expected. Individuals who have greater WM capacity tend also to be less susceptible to interference, a result that replicates the results when the Stroop task and others have been used (e.g., Long & Prat, 2002). However, it is also clear that WM and susceptibility to interference are not totally overlapping constructs. When shared sources of variance are accounted for, WM specifically predicts the rate of uncertainty responses to the AC and DA inferences. This is consistent with the idea that such responses require the retrieval of alternate antecedents (Markovits & Quinn, 2002), which is, in turn, facilitated by WM capacity (Rosen & Engle, 1996). Correspondingly, differences in susceptibility to interference specifically predict the rate of inappropriate responses to the MP and MT inferences, something that is consistent with the idea that some form of executive control is required to prevent interference by potential disabling conditions (Markovits & Potvin, 2001).

In addition, analysis of latency measures appears to indicate the presence of two different patterns characterizing reasoners with differences in susceptibility to interference. Among reasoners with a relatively high WM capacity, making errors in the sentence completion task was associated with generally shorter latencies, whereas for reasoners with relatively low WM capacity, the opposite was true. This suggests that, for high-WM reasoners, less susceptibility to interference is associated with a form of strategic planning—that is, reasoners who take more time in making their judgments make fewer errors on the sentence completion task with related nonwords and fewer inappropriate inferences on the MP and MT forms (see Long & Prat, 2002, for similar results with the Stroop task). This would, in turn, imply that for these reasoners, failure of inhibitory control is due not to a basic inability to inhibit inappropriate information, but to use of an inappropriately rapid processing strategy. In contrast, for reasoners with a relatively low WM capacity, those who respond

more quickly make fewer errors on the sentence completion task. This is a novel result, and it is not clear why this should be the case. One possibility is that for these subjects, the relative difficulty in suppressing interference due to inappropriate information represents a basic failure in competence, one that is not resolved by slowing down speed of judgment.

Overall, these results reinforce the idea that an important component in reasoning logically with concrete premises that are not empirically true is suppression of interference due to inappropriate information that might be activated during reasoning. Such a process can be seen as a counterweight to the developmental increase in the ability to retrieve both appropriate and inappropriate information about premises (Janveau-Brennan & Markovits, 1999). Since retrieval efficiency has been linked to WM capacity (Rosen & Engle, 1996), this suggests that suppression of interference and WM, although partially overlapping in some respects, might well be complementary aspects of the cognitive system.

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