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Everyday Conditional Reasoning with Working Memory Preload

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Abstract

There are two accounts explaining how background information can affect the conditional reasoning performance: the probabilistic account and the mental model account. According to the mental model theory reasoners retrieve and integrate counterexample information to attain a conclusion. According to the probabilistic account reasoners base their judgments on likelihood information. It is assumed that reasoning by use of a mental model process requires more working memory resources than solving the inference by use of likelihood information. We report a thinking-aloud experiment designed to compare the role of working memory for the two reasoning mechanisms. It is found that when working memory is preloaded participants use less counterexample information, instead they are more inclined to accept the inference or to use likelihood information. The present results add to the growing evidence showing that working memory is a crucial determinant of reasoning strategy and performance.

Introduction

There is evidence for a general link between working memory capacity and performance in a range of reasoning tasks (see e.g., Barrouillet, 1996; Gilhooly, Logie, & Wynn, 1999; Kyllonen & Christal, 1990). Previous studies showed that skilled reasoners generally give more normative answers and follow a high demand reasoning strategy (see e.g., Copeland & Radvansky, in press; Gilhooly, Logie, & Wynn, 1999). It is assumed that these normative answers are obtained by an analytic reasoning mechanism that hinges on working memory capacity (Klauer, Stegmaier, & Meiser, 1997; Meiser, Klauer, & Naumer, 2001). The present research continues this line of research and concerns causal conditional reasoning with everyday sentences.

Without labeling conclusions as (in)valid, we will investigate how people solve the following two conditional inferences with everyday causal sentences:

Modus Ponens (MP)
If cause, then effect
Cause occurs.
Does the effect follow?

Affirmation of the Consequent (AC)
If cause, then effect
Effect occurs.
Did the cause precede?

Examples of everyday ‘if cause, then effect’ sentences are:
If you phone someone, then his telephone rings.
If you eat salty food, then you will get thirsty.
If someone has a high income, this person will be rich.
If a dog has fleas, then it will scratch constantly.

Abundant research established that when people reason on everyday conditionals, they spontaneously bring relevant background knowledge into account (for a review see Politzer & Bourmaud, 2002). This contextualization process is characteristic for common-sense reasoning and is responsible for our ability to adaptively cope with everyday situations. The current study focuses on how background knowledge is used for deriving conditional inferences.

There are two reasoning mechanisms describing how background information is used during reasoning. First, according to the probabilistic account reasoners derive the probability that the conclusion follows given the categorical premise and use this probability to draw a gradual conclusion (Lui, Lo, & Wu, 1996; Oaksford, Chater, & Larkin, 2002). For MP, reasoners will confine their knowledge base to the situations where the cause occurs. Based on this range of situations they then determine the likelihood that the effect follows. If they can induce that a particular effect always or mostly follows the cause, they conclude that the effect will (probably) follow. The endorsement of MP is thus directly proportional to L(effect|cause). AC is solved in analogy with MP. Reasoners activate all relevant situations where the effect occurs. Within this subset they infer the likelihood that the cause preceded the occurring effect. This likelihood L(cause|effect) directly reflects the AC acceptance rate.

According to the second reasoning mechanism the conclusion is attained by taking possible counterexamples into account. There is a strong and reliable effect of the number of available counterexamples on inference acceptance (see e.g., Cummins, Alksnis, Lubart, & Rist, 1991). The mental models theory describes how participants reason with counterexample information (Johnson-Laird & Byrne, 1991; Markovits & Barrouillet, 2002). When given a problem based on a causal rule, for instance, ‘*If you water a plant well, the plant stays green*’, reasoners will start by representing the content of the conditional as a possibility: It is possible that a plant is well watered and green. Active consideration of the problem content will then lead to an automatic activation of relevant background information. This information is used to complement the initial model. For MP and MT, the categorical premise triggers the retrieval of disablers. Some examples of disablers are: 'the plant caught a disease' or 'the plant was deprived of sunlight'. When reasoners retrieve at least one disabler, they do not conclude that the effect follows. For AC an automatic search for alternative causes starts, for example, 'the lack of water was compensated by adding fertilizer' or 'the plant is a succulent'. When reasoners retrieve an alternative cause, their mental models inform them that there are two conclusions possible (watered and not watered). As a result, they do not accept the default conclusion.

It is clear that the probabilistic and the mental model reasoning mechanisms both rely on available background information, but they focus on a different *type* of background knowledge: probabilities versus exemplars. Both information types have already been brought together by, e.g., Weidenfeld & Oberauer (2003); Verschueren, Schaeken and d'Ydewalle (2003; 2004a) integrated the two theories that explain how the information is taken into account in a dual process perspective. They label the probabilistic mechanism as heuristic and the mental model mechanism as analytic. Heuristic processes are generally considered as fast, automatic mechanisms that operate at a low cognitive cost and at the periphery of awareness. Analytic processes are generally slower, more demanding reasoning mechanisms that operate in a conscious and strategic manner (Stanovich & West, 2000). Verschueren et al. (2004a) manifest three reasons for linking the two reasoning processes to a heuristic-analytic polarity. (1) The heuristic reasoning process is mainly implicit - reasoners have no recollection of the range of situations that are taken into account to calculate a likelihood estimate whereas people reasoning by use of mental models are conscious of the counterexample(s) they retrieve. (2) The process based on likelihood information yields relatively fast results whereas using counterexamples requires a sequential thus slower reasoning process. (3) The heuristic conclusion is overwritten when a more analytical conclusion can be produced (see Verschueren, et al., 2004a for experimental evidence for 2 and 3). At present we will investigate whether both reasoning mechanisms differ in their working memory demands. If indeed the mental model account describes an analytical reasoning mechanism it should pose more demands on working memory capacity than the heuristic likelihood process.

Experiment

It is assumed that reasoning with counterexample information draws heavily on working memory resources, whereas the use of mere likelihood estimates imposes a far lesser demand on working memory. When participants reason based on counterexample information, the problem content as well as all models of relevant situations have to be represented. The larger the number of mental models that participants have to represent and maintain, the heavier the load on working memory during reasoning (Barrouillet & Lecas, 1999). Additionally, it has been found that counterexample retrieval efficiency suffers from dual task loads, which indicates that working memory is also involved in the retrieval of counterexample information (De Neys, 2003). In case the reasoners have a representation of both the conditional sentence and at least one counterexample, they subsequently have to integrate this information to see that there are two different conclusions for the same problem. This information manipulation and integration is considered as a crucial task of working memory.

For the reasoning process based on likelihood information, the demands on working memory are far less. The situations used for attaining a likelihood estimate are not actively represented in working memory, but rather briefly accessed. There is neither an active controlled search process nor a need for premise integration. The likelihood estimate is based on all relevant situations at a time and the final conclusion directly mirrors the obtained likelihood estimate.

When reasoners are asked to think aloud during reasoning, we can monitor which information they use for deriving conclusions. By concurrently checking the information that people use we get a direct indication of the underlying reasoning process. Only in case where people do not provide extra information but accept the conclusion without further argumentation, this procedural aspect is unclear. It can be that participants did use their background knowledge and found that the likelihood that the conclusion follows is sufficient to grant acceptance or that there are no counterexamples available. Or else it can be that they did not rely on background information and just satisfied the conclusion by restating the given information.

In a previous thinking-aloud study Verschueren, Schaeken and d'Ydewalle (2004b) showed that participants with low working memory capacity more often use likelihood estimates to solve an inference, whereas participants with a larger working memory capacity rather use counterexample information. These results can be considered as an indication for the difference in working memory demands of the heuristic and analytic process. This setup provides however only *correlational* evidence. Indeed, it is still possible that a third factor (e.g., general intelligence, motivation, etc.) explains both the performance on working memory tests as well as on reasoning tasks. The following experiment was designed to test whether there is a difference in the actual working demands of the two processes.

In this experiment we examined the effect of secondary task interference on the applied reasoning mechanisms. In the dual task methodology, a secondary task chosen to burden working memory capacity has to be carried out concurrently to the criterion task. The degree of disruption in the criterion task under dual task conditions – as compared to single task conditions – is taken to reflect the dependence of the criterion task on working memory. The criterion task we used was a thinking-aloud conditional reasoning task. Concurrent verbalization allows us to monitor the information that reasoners consult for deriving conclusions. By checking the information that people refer to (likelihood or counterexample information) we get a direct indication of the underlying reasoning process.

Because the criterion task entails spontaneous verbalization, the choice of secondary tasks is limited. Pilot work revealed that concurrent motor, auditory or articulatory activity interfered with the participants verbalization. We therefore opted for a preload paradigm. Because a spatial load is less likely to interfere with verbalization than a verbal or numerical load, we worked with a spatial preload set-up. The evidence that spatial storage tasks tap a working memory feature crucial for reasoning is twofold: Klauer, et al.(1997) report that a concurrent spatial load led to a significant disruption of propositional (including conditional) reasoning. Second, in the visuospatial domain simple storage tasks have a similar correlation with executive functioning and reasoning as classic processing-and-storage tasks (Miyake, Friedman, Rettinger, Shah, & Hegarty, 2001; Suess, Oberauer, Wittman, Wilhelm, & Schultze, 2002). We can thus assume that the preload task taps working memory resources that are needed for reasoning, while at the same time minimizing a possible interference with the verbalization process. The dot memory task we used is a classic simple storage task (adapted from Miyake, et al., 2001; Oberauer, Suess, Wilhelm, & Wittman, 2003). We briefly presented a 3x3 matrix with 4 dots forming a complex pattern, afterwards participants were asked to reproduce this dot pattern.

In the preload-condition participants had to memorize the pattern of the dots while solving a reasoning problem. We will verify whether the use of counterexample information decreases when working memory is preloaded, compared to performance in the control condition. The decreement in the use of likelihood information should be significantly smaller than the decreement in counterexample use.

Method

Participants A total of 52 first year psychology students participated in the study.

Procedure and Design The participants were tested individually. The experiment was run on computer. Participants started by reading the instructions. They were told that they will be asked to think aloud while solving conditional inference problems. The reasoning instructions read that they should answer the question as in an everyday setting. Each participant then solved two test problems, e.g.,

> If someone catches a cold, then he will cough.
> Someone coughs.
> Did this person catch a cold or not?

The participants read the premises aloud and answered immediately. When they found that they had completed their answer, they pressed a key to go to the following problem. After the presentation of the reasoning instructions, the participants either reasoned with or without working memory preload. In the preload conditions participants started by practicing two dot patterns: A pattern was presented for 500ms and participants were immediately asked to reproduce this pattern. The overall performance on the test problems was nearly perfect. After these dot pattern practice trials, participants were given instructions for reasoning under preload. First, a dot pattern was presented for 500ms, next the reasoning problem occurred, participants read the premises aloud and answered immediately. The answers participants gave were recorded on tape. When they finished their answer, they pressed a key and a blue screen appeared where they were asked to reproduce the dot pattern. When they completed the dot pattern, they pressed a key to start the next trial. It was explicitly mentioned that they had to memorize the dot patterns correctly; they were told that an incorrect reproduction rendered the trial invalid. This was done to make sure that participants actively attended the dot pattern and tried their best in memorizing it. In the control condition, the dot patterns were presented for 500ms before the premise presentation. Participants were told that these dot patterns are presented as a control condition, they were asked to look at the dot patterns but not to memorize them. They read the premises and pressed a key when their answer was complete, the next trial started immediately. The time that participants needed to read and solve the reasoning problem was measured.

Materials and Design Based on previous research we selected 12 sentences with a maximally varying necessity and sufficiency of the cause (maximal variation in L(effect|cause), L(cause|effect), and in the number of available disablers and alternatives). We made sure that the reading time of all 12 sentences was comparable ($M_{\text{number of words}} = 9.5$, SD = .314). Twenty-six participants solved 12 AC inferences; the others solved 12 MP problems. The 12 sentences occurred always in the same order; the causes of the first six sentences and the last six sentences were equally necessary and sufficient. For both reasoning forms, half of the participants solved the first six problems under preload; the other six problems were solved without preload (control condition). For the other half of the participants the order of the preload/control conditions was reversed. Because we used 12 different sentences, transfer effects between the two conditions could be excluded.

Results

The obtained reasoning answers were literally transcribed. Next, the condition-codes were removed and the answer types were rated. It was indicated whether the answer reflected a simple acceptance of the default conclusion or whether there was reference to a counterexample or to a likelihood estimate. There was no overall difference in the average response time for the preload (18.19s) and the control condition (18.53s). In the control condition, there was 26% inference acceptance, in 22% of the trials participants used likelihood information and in 64% they referred to counterexamples. These results are similar to those observed by Verschueren et al. (2004a; 18%, 18% and 66% respectively).

In the preload condition there were 6.4% combination trials (in a ‘combination trial’ participants refer to counterexample and likelihood information) whereas in the control condition there were 23.1% combination trials. The observation that combining the two types of information becomes less prevalent when working memory is preloaded, suggest that the information integration process that is characteristic for combination answers taps on working memory resources. For comparing the relative importance of both reasoning processes, we confined the analysis to trials where participants either referred to a likelihood or to counterexample information. Combination trials were excluded from the analysis (14.4%).

Task interference. Only 69% of the dot patterns were reproduced correctly. There was an effect of answer type on the correct reproduction of the dot patterns, *F(*2, 21) = 6.696, *p* < .01 (*Wilks’ lambda* = .611). This interaction is displayed in Figure 1. When the dot patterns were correctly reproduced, there were fewer counterexamples mentioned than when the dot patterns were incorrectly reproduced*, F*(1, 22) = 11.96*, MSE* = .458, *p* < .05. On the correctly reproduced trials, there were more answers where participants referred to likelihood information, *F*(1, 22) = 5.21, *MSE* = .037, *p* < .05. There was no significant effect on the inference acceptance rates. These results reflect a *task interference*. When participants rely on a reasoning process that puts only a minor demand on working memory there are enough resources left to maintain and reproduce the dot pattern. In contrast, when participants rely on retrieval, manipulation and integration of counterexample information, working memory capacity is severely burdened. There are then not enough resources left to actively maintain the dot patterns, resulting in an incorrect reproduction. These results support the idea that using counterexample information draws heavily on working memory resources.

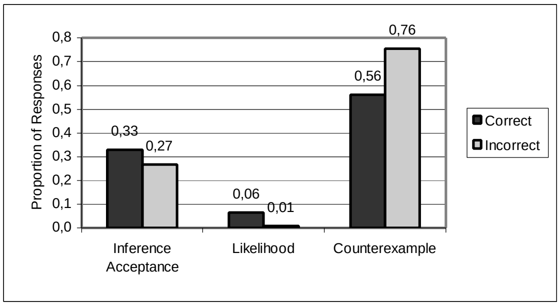

Figure 1: Difference in the proportion of the three types of answers for preload trials where the dot pattern was correctly versus incorrectly reproduced.

Effect of preload on the reasoning process. For examining the effect of preload on the types of answers, we only included the preload trials where the dot pattern was correctly reproduced. All analyses were run on proportions; the number of times each answer type occurred was divided by the total number of correctly reproduced trials. We ran an analysis of variance with sentences as the unit of analysis, and a 2 (inference type, between subjects) * 2 (preload, within subjects) * 3 (answer type, within subjects) design. We found a main effect of answer type. There were more answers referring to counterexample information (60.1%) than there was plain inference acceptance (27.7%) or likelihood information used (5.6%), F(2, 21) = 102, 72, p < .001 (*Wilks’lambda* = .08). The interaction between answer type and preload condition was marginally significant, *F*(2, 21) = 3.120 *p* = .065 (*Wilks’lambda* = .771). Figure 2 illustrates this interaction. There was a clear yet marginally significant decrease in the use of counterexample information when working memory was preloaded, *F*(1, 22) = 3 304, *MSE* = 0.078, *p* = .082. There were significantly more inferences accepted in the preload condition, *F*(1, 22) = 8.255, *MSE* = 0.131, *p*<.01 while there was no significant increase in the use of likelihood information. No other interaction effects reached significance. The observation that there is more inference acceptance under preload corroborates previous effects of secondary task load on the conditional reasoning performance (De Neys, 2003).

The explanation provided by De Neys (2003) is that under preload, the resources available to participants are insufficient to retrieve counterexample information. The currently observed decrease in counterexample use is in line with this explanation. The increase in inference acceptance can also be - at least partially - related to an enhanced matching heuristic. We can assume that some reasoners do not engage in an active reasoning process based on counterexample retrieval, but simply restate the information from the conditional and blindly accept MP and AC. In this case the preloading should cause more participants to accept all conclusions, even on sentences where counterexamples can be automatically retrieved and likelihood estimations are high. In the preload condition, there were indeed more participants (13.5%) who accepted at least 75% of the inferences than in the control condition (7.7%). Even for sentences with many available counterexamples – for these sentences counterexamples can be retrieved automatically and likelihood estimations are very low - we found an increase in the inference acceptance rates (7.1% control vs. 19.8% preload). This shows that it is unlikely that participants consulted their background knowledge for deriving the conclusion and lends support for the hypothesis that the working memory preload led to an enhancement of the computationally low demanding matching heuristic.

In sum, as expected the resource dependent use of counterexample information decreased under preload, while the use of likelihood information was unaffected

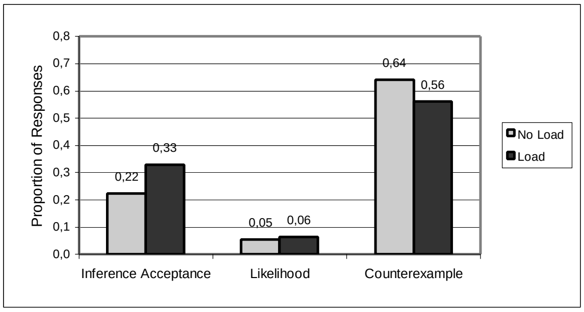

Figure 2: Proportion of answers of the three types for the preload versus control condition (only preloaded trials with correctly reproduced dot patterns).

by preload conditions. The decrease in use of the counterexample based reasoning process is at least partly compensated by shifting to inference acceptance.

Number of counterexamples used. Does the decrease in the use of counterexample information under preload reflect a decrease in a strategic validation tendency? If participants retrieve counterexample information to merely check whether the default conclusion can be falsified (see e.g., Schroyens, Schaeken, & Handley, 2003) they would need to retrieve only one counterexample to falsify the given conclusion. However, we did not find a difference in the number of trials where participants referred to only *one* counterexample (preload: 73% vs. control-condition: 82.4%). This raises doubt on the validation-hypothesis. In contrast, we observed a decrease in the proportion of trials where *more than one* counterexample was mentioned, $t(23) = 2.77$, $p < .05$ (preload: 17% vs. control-condition: 26%). This underscores the idea that in tasks without deductive instructions reasoners retrieve counterexample information to provide an adequate and informative conclusion rather than to merely falsify a default conclusion. When looking at the *total number* of specific counterexamples used, there were significantly more counterexamples used in the control condition (1.09) than when working memory was preloaded (0.86), $t(23) = 3.97$, $p < .01$.

If counterexample retrieval, representation and integration demand effort, we should observe an effect of counterexample retrieval on the secondary task performance. We tested whether there was a difference in the number of counterexample answers for the trials where the dot pattern was correctly versus incorrectly reproduced. We included the number of available counterexamples (few/many; measured by the generation task) because it is a strong predictor of counterexample use. There was a marginally significant interaction between the number of counterexamples used and the (in)correct reproduction of the dot pattern, $F(1.20) = 4.120$, $MSE = 2.866$, $p = .056$. Pairwise comparisons revealed that for sentences with many available counterexamples there were significantly more counterexamples produced when the dot patterns were not recalled correctly, $F(1, 20) = 6.946$, $MSE = 4.832$, $p<.05$ (not significant for few-sentences). This converges with the observed interference of counterexample use and correct dot pattern recall.

In general, these results sustain the idea that using counterexample information draws heavily on working memory resources whereas using likelihood information or matching is less resource demanding.

Discussion

Correlational studies revealed that differences in working memory capacity relate to differences in the conditional answer patterns. A possible explanation is that differences in reasoning performance do not simply relate to differences in a single reasoning predisposition, but are mediated by differences in the working memory demands of the active reasoning mechanisms. Highlighting the distinction between more heuristic strategies (such as matching and likelihood use) and more cognitively demanding analytical strategies (relying on counterexamples) may provide a more differentiated picture of the specific role of working memory in conditional reasoning. We found evidence for two conditional reasoning mechanisms with a differing working memory demand: a probabilistic account relying on likelihood information and a mental model account relying on counterexample information.

The results reveal that using counterexample information to attain a conclusion taps heavier on working memory resources than deriving the conclusion based on likelihood information. This provides additional support for considering the reasoning process based on likelihood information as heuristic and the reasoning process based on counterexample information as analytic. The differences in use of counterexamples/likelihood on participants with varying working memory capacity observed by Verschueren et al. (2004b) may thus be attributed to the working memory demands of the two reasoning mechanisms.

We found a large effect of working memory preload on the inference acceptance rates. When relating inference acceptance to the two reasoning strategies, it can reveal that either no counterexamples can be retrieved or that the likelihood estimation is sufficiently high. However, because we also observed an increase in inference acceptance on sentences for which pretests revealed many available counterexamples as well as likelihood estimates that are well below 1, it rather seems that the inference acceptance rates show that under preload some reasoners do not consult their background knowledge. When working memory capacity is burdened by preload, these participants are discouraged to engage in a demanding retrieval process. Instead they provide an answer that satisfies the inference question, simply by restating information from the premises. This strategically placed escape hatch can explain the increase in inference acceptance rates under preload.

Taken this together, we found evidence for the involvement of working memory in conditional reasoning. By analyzing the answers participants gave we were able to pinpoint which information participants used to attain their conclusion. We found support for distinguishing two heuristic reasoning strategies -use of likelihood information and matching- and for an analytic strategy that takes counterexamples into account. Working memory preload yielded an increase in the use of heuristic strategies whereas the use of the analytical strategy decreased.

The present study is one of the first to combine a secondary task paradigm with a verbalization criterion task. Using a preload-paradigm is probably the best way to investigate the working memory demands of tasks involving verbalization. Although we cannot be entirely conclusive on a possible secondary task interference on verbalization processes (the answers were structurally similar to baseline results) this procedure enabled us to experimentally test the difference in working memory demands.

The effect of working memory capacity on inference making is at present only discussed on an intensive level: We investigated the *global* effect of a working memory dependent secondary task on the use of likelihood and counterexample information. Whether the working memory demands of the two processes coincide with the assumed differences in representation, retrieval and manipulation cost cannot be decided upon based on the present results. The data may also reflect the cost of determinacy: Giving a gradual uncertain answer may be overall less demanding than providing a determinate conclusion. There is also no information about the relative functional involvement of the different working memory components. Specific research with different types of well-chosen secondary tasks may reveal this crucial information.

In sum, distinguishing different reasoning mechanisms that can be used to solve conditional inferences can enhance our comprehension of how working memory mediates the reasoning performance. The specific working memory demands of different reasoning strategies co-determine the robust effect of working memory capacity on the conditional reasoning performance.

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