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Two Reasoning Mechanisms for Solving the Conditional 'Fallacies'.

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Abstract

There are two different reasoning mechanisms for solving 'if-then'-problems: one is based on likelihood-estimates and is rather heuristic; the other one takes counterexamples into account and is analytic in nature. Based on the difference in input of the two reasoning mechanisms we found that the AC problem is mainly solved by using likelihood-information, whereas the DA problem is rather solved using counterexample-information. Mental models adepts have proposed some explanations to account for the differences in processing difficulty and speed between AC and DA. Considering the reasoning mechanism for AC and DA from a dual process perspective provides an extra explanation for the observed effects. This study indicates that framing observations in a dual process account can provide additional explanations for well-known phenomena.

Introduction

Reasoning with conditional sentences is one of the central activities of our daily life. By using conditionals people are able to predict and explain the occurrence of simple as well as complex effects. There are situations in which these inferences are made in an effortless and unconscious manner, in other situations reasoners consciously initiate a range of steps leading to a conclusion. This difference can be framed within the general idea of dual processes (see e.g., Evans & Over, 1996; Sloman, 1996; Stanovich & West, 2000). The dual process theories bear a family resemblance in distinguishing two types of cognitive processes. One process operates in a fast, heuristic, implicit way and leads to pragmatic conclusions. The other process is characterized by rather slow, analytic and explicit way of processing and yields more normative answers. In general the dual process theories suffer from a trade-off between scope and precision. The theories apply to a whole range of tasks: text comprehension, attribution, induction as well as deduction tasks, but in their general formulation they are not suited to make precise predictions in specific task contexts (see e.g., Sloman, 1996; Osman, 2002).

The present article focuses on how simple everyday causal conditional arguments are solved. There are four conditional problem types: (1) modus ponens, MP: 'if p, then q', 'p', 'q follows' (2) modus tollens, MT: 'if p, then q', 'not q', 'not p follows' (3) affirmation of the consequent, AC: 'if p, then q', 'q', 'p follows' and (4) the denial of the antecedent, DA: 'if p, then q', 'not p', 'not q follows'. These four conclusions are the default conclusions; when reasoners give this conclusion, we say that they accept the inference.

In classical logic, MP and MT are considered valid inferences, whereas AC and DA are labeled fallacious. The distinction between valid inferences and 'fallacies' does not hold in everyday reasoning. The distinction valid/invalid is based on the material implication interpretation of the 'if-then' connector: 'p' is sufficient but not necessary for 'q'. In everyday (causal) reasoning there are sentences of all four possible combinations of sufficiency and necessity, so the material implication interpretation is just one out of four possible interpretations of 'if-then'. In general, instead of considering the formal structure of the argument, reasoners draw a conclusion based on the problem content, namely whether the cause is necessary and/or sufficient for the effect (see e.g., Cummins, Lubart, Alsknis, & Rist, 1991; Thompson, 1994; Cummins, 1995; Newstead, Ellis, Evans, Dennis, 1997). Although the truth-functionality of the material implication does not apply to everyday reasoning in general, some reasoners can still take the *logical* validity of the inferences into account. Markovits and Barrouillet (2002) and De Neys, Schaeken, and d'Ydewalle (2003) claim that skilled reasoners can inhibit 'relevant' disabling information when they are solving MP and MT; even when the cause is not sufficient for the effect, MP and MT are still accepted. To avoid this possible interference of logical validity on the reasoning mechanism the present research will be confined to the solving of the so-called fallacies, AC and DA.

To find out how AC and DA are solved, we elaborate on the question posed by Cummins (1995): Can naive human reasoning best be characterized as an inductive probabilistic process or is our naïve understanding based on the consideration of alternative causes and disabling conditions?

To answer this question the two processes are linked to two recent theories on deduction: the mental model account and the probabilistic account. The two processes are brought together in the dual process theory formulated by Evans and Over (1996), but the specification can also be linked to other dual process accounts. There is already evidence for this dual process specification for causal conditional reasoning: it was found that the heuristic reasoning mechanism delivers a fast output and uses likelihood-information as input, whereas the analytical process takes more time to produce a conclusion and takes counterexamples into account (Verschueren, Schaeken, & d'Ydewalle, 2003a). In this specification both reasoning mechanisms that Cummins proposed can be recognized: The heuristic process corresponds roughly to the inductive probabilistic process, whereas the analytical process focuses on counterexample retrieval. In general the characteristics of the two reasoning mechanisms for causal reasoning are summarized in Table 1.

Table 1: Characteristics of the specified dual process theory.

Heuristic mechanism
Consists of a single phase
Yields fast results
Implicit: only end-product is available to consciousness
Minor load on working memory capacity (automatic)
Rather pragmatic result
Analytical mechanism
Reasoning mechanism is a sequential process
Relatively slow process
Explicit: reasoner is conscious of the retrieved counterexample(s)
Influenced by working memory capacity
Rather normative result

Meta-analytic studies indicate that AC is endorsed more frequently than DA. Additionally, it takes reasoners longer to solve DA than to solve AC (Schroyens, Schaeken, d'Ydewalle, 2002; Barrouillet, Grosset, & Lecas, 2000). In the present article these differences in processing difficulty and speed are approached from the perspective of dual processes. It is possible that the observed differences between AC and DA emerge from the characteristics of the process by which the inferences AC and DA are mainly solved. For instance, when the fast heuristic process is more important for solving AC than for solving DA, then the difference in problem solving time can already be explained.

The central question of the present article is: How are AC and DA solved; what is the relative importance of the analytical and heuristic reasoning processes? First, we will outline how the two inferences are solved according to the analytical and the heuristic process specification.

Analytical process

The specification of the analytical reasoning mechanism is based on a recent variant of the mental models theory proposed by Markovits and colleagues (see e.g., Markovits, Fleury, Quinn, Venet, 1998; Barouillet, Markovits, & Quinn, 2001; Markovits & Barouillet, 2002). How AC and DA are solved according to this theory will be illustrated with the sentence: '*If you pull a cat's tail, then the cat will get angry'*. Regardless of the inference type, reasoners start the reasoning process by representing the content of the causal rule as a possible situation (initial model): '*pull tail, cat angry'* (1). The theory assumes that the active consideration of the problem content will lead to a semantic activation of relevant information from long-term memory. This retrieved information is used to extent the initial model. In case of DA, the categorical premise contains a negation and will strongly activate the complementary class. So after the initial model construction, reasoners will retrieve the following model: '*don't pull tail, cat not angry*' (2). The construction of this second model is reserved for DA, it is not constructed in case of AC. The retrieval process can stop here, but not necessarily; other relevant information structures can still be accessed automatically.

For AC and DA, the active consideration of the conditional and the categorical premise will cue an automatic search for alternative causes.[1] An alternative cause is a cause other than the given cause 'p' that can also produce the effect 'q'. Examples of alternative causes for the sentence '*If you pull a cat's tail, then the cat will get angry'* are*: take away its food, throw something at it, pull its ear….* In general, the alternative cause has the following structure: '*don't pull tail, cat angry'* (3).

Depending on whether reasoners retrieve an alternative cause, they will accept or reject the default conclusion. First for AC, when reasoners do not retrieve an alternative cause, they only have a representation of the initial model (1); in this case they will accept the default conclusion 'p', because they have not found other situations leading to a different conclusion. In case reasoners retrieve an alternative cause, they have a representation of (1) and (3). This representation informs them that there are two possible causes for the given effect. So, they will not accept AC. For DA, we follow the same line of reasoning. When reasoners do not retrieve an alternative cause, they have a representation of (1) and (2). This leads them to accept the inference because to their knowledge there is only one possible consequence linked to 'not p', that is 'not q'. In case reasoners do retrieve an alternative cause, they have a representation of (1), (2) and (3). These three models lead them to the insight that there are two possible conclusions for 'not p'- namely 'q' and 'not q'- hence they do not accept the default DA conclusion.

Heuristic process

In the heuristic process the conclusion is based on probabilistic properties (see e.g., George, 1997; Lui, Lo & Wu, 1996; Oaksford, Chater & Larkin, 2000; Stevenson & Over, 1995). For solving causal conditional problems, reasoners base their heuristic answer on conditional likelihood estimates. The likelihood that the effect is produced by the cause L(p|q) is used for solving AC and DA.

For AC, reasoners have to infer what caused the consequent 'q' to take place. To solve this problem heuristically they will consider the categorical premise, 'q'

[1] This retrieval process is not overall 'automatic', working memory is needed to actively generate cues for retrieval (De Neys, Schaeken, & d'Ydewalle, 2003). Verschueren, De Neys, Schaeken, & d'Ydewalle (2002) also found that the types of counterexamples that reasoners generate differ according to the working memory capacity of the reasoners.

and automatically activate all situations that are relevant to 'q'. Based on the range of relevant situations, reasoners then induce L(p|q). Based on this likelihood reasoners immediately draw their conclusion; when the likelihood is high, they will accept AC, when the likelihood is low, they will not accept the inference (see also Oaksford et al., 2000). AC acceptance is in direct proportion to L(p|q).

For DA the heuristic reasoning mechanism based on L(p|q) is less intuitively clear. Oaksford et al. (2000)'s core reasoning principle is that reasoners endorse an inference in direct proportion to the likelihood that the conclusion follows given the categorical premise, for DA this would be L(not q | not p). However, the categorical premise of DA contains a negation and it is difficult to base a likelihood-estimate on a negative proposition. The main problem lies in the contrast class that is constructed when processing a negation (Oaksford & Stenning, 1992; Schaeken & Schroyens, 2000; Schroyens, Schaeken, & d'Ydewalle, 2001; 2002). If you have to access all situations that are relevant to for instance, 'not a dog' you have to look at 'a cat or a bird or a fish or a sheep or a cow or…' It seems unlikely that DA is solved by use of a likelihood-estimate based on a range of disjunctions. In previous research it is found that the linear correlation between the proportion of DA acceptance and L(p|q) is higher than the correlation between DA acceptance and L(not q|not p) (R(DA, L(p|q))=.870, R(DA, L(not q|not p)=.561, both N=20, $p<.05$). This indicates that the likelihood used for solving DA is L(p|q) rather than L(not q| not p). Indeed, it has repeatedly been found that the likelihood-estimate L(p|q) is strongly related to the percentage of DA acceptance (see e.g., Thompson, 1994). Verschueren et al. (2003a) propose a suppositional strategy that makes clear how L(p|q) is used to solve DA. The DA inference is based on the supposition that 'q' is the case. Then by use of L(p|q) they heuristically infer 'p' (AC). Reasoners are then faced with a gradual contradiction between their tentative AC-conclusion about the likelihood of 'p' and the categorical premise 'not p'. This contradiction will result in a proportional rejection of the supposition 'p' and a proportional acceptance of the conclusion 'not p'. When the L(p|q) is high, DA will be accepted more, when L(p|q) is low, DA will be less accepted. These rule-like steps of reasoning for solving DA are supposed to function in an automatic and associative mode.

Relation between both processes

From a theoretical point of view the relation of both processes has to be considered. It is assumed that heuristic processes start automatically and by default. When the analytical process reaches a conclusion, it overrides the output given by the heuristic process (see e.g., Evans & Over, 1996; Stanovich & West, 2000). This override-principle is the centerpiece of the relation between the heuristic and analytical processes and also applies to the specified dual process theory. The are two possible interaction scenario's: either both processes produce their conclusion in relative isolation from each other, or the output of the heuristic process is used as input for the analytical process. In the latter case the long term memory information needed to construct the initial model 'p-q' can be used in a heuristic manner using L(p|q). But we refrain from speculating about the specific interaction mechanism. We confine ourselves to the psychological reality of both processes.

Experiment

When seeking to investigate which of the two processes are involved in reasoning, we have to pinpoint the crucial difference between both reasoning mechanisms. Both mechanisms appeal to long term memory information but there is a fundamental difference in the way this information is conceptualized. The heuristic process uses likelihood-information; this information is gradual and concerns a generalization of all relevant situations. The analytical process uses information about alternative causes; the additional model is constructed only in case an alternative cause is retrieved. In deductive reasoning tasks this leads to a discrete effect on inference acceptance: When the alternative model is constructed, reasoners reject the inference, otherwise they accept the inference.

It has been shown that the availability of alternative causes in long term memory as well as likelihood-estimates affect the inference acceptance rates of AC and DA (Thompson, 1994; Cummins, 1995; Stevenson & Over, 1995). In the paradigm that Verschueren et al. (2003a) used to investigate the importance of both reasoning mechanisms, the difference between the heuristic and analytic information input is used to determine the relative importance of both processes. One group of participants is asked to rate L(p|q), another group of participants will check whether there are alternative causes and a third group of participants is asked to solve reasoning problems based on the same sentences. By using multiple regression analysis it is possible to investigate which information type (likelihood or counterexample) accounts for most of the observed variance in acceptance ratings.

Method

Design 291 psychology students participated as part of course requirements. The participants were divided in three groups. One group of 23 participants provided likelihood information on 43 sentences. A second group of 23 participants provided counterexample-information. These participants determined for all 43 sentences whether there are alternative causes possible. A third and large group (N=245) was given the reasoning problems. Each participant received 16 problems based on 16 different sentences that are randomly selected from the pool of 43 sentences. There were 4 MP presented, 4 MT, 4 AC and 4 DA. Only the AC and DA rates will be considered.

Material The 43 sentences were selected based on previous research. The selection made sure that there was a representative sample of everyday causal sentences. The sentences concerned different semantic domains and there was a nearly equal number of sentences with causes that are (a) necessary and sufficient for the effect (b) necessary but not sufficient, (c) not necessary but sufficient and (d) neither necessary nor sufficient.

The likelihood-rating was constructed so that the result of the rating mirrors the input of the heuristic process. Each rating consisted of the conditional sentence and a subsequent question, for instance: <u>Sentence</u>: *'If you pull a cat's tail, then the cat will get angry'*. <u>Rating</u>: *'A cat is angry, did someone pull its tail?'* Participants were asked to rate a likelihood, they had to choose from: '*never / seldom / sometimes / often / always*'. Never was scored as 1, always was scored as 5.

The counterexample-rating mirrored the result of the analytical retrieval process, namely: whether people could retrieve an alternative cause. The counterexample-rating looked as follows: <u>Sentence</u>: *'If you pull a cat's tail, then the cat will get angry'*. <u>Rating</u>: *'Can a cat get angry without someone pulling its tail?'* Participants chose '*yes*' or '*no*'. Yes was scored as 0, no was scored as 1.

The reasoning problems were presented in an evaluation format. An example of AC: <u>Sentence</u>: *'If you pull a cat's tail, then the cat will get angry'*. <u>Situation</u>: *A cat is angry.* Participants were asked to choose one of four <u>conclusions</u>: *(1) Someone pulled its tail (2) Someone did <u>not</u> pull its tail (3) It is possible that someone pulled its tail, but it is also possible that its tail was <u>not</u> pulled (4) I don't know.* Inference acceptance (1) was scored as 1, all other answers were scored 0.

Procedure All participants were tested collectively at the same time, the two rating tasks as well as the reasoning task were presented in paper-pencil format. The participants were divided in three groups and received instructions according to the task they had to perform. For the reasoning task, the participants were instructed to solve the problems as in an everyday setting. No instructions concerning logical deduction were given.

Results

For each of the 43 sentences we obtained the mean L(p|q) (M=3.56, SD=.775), the mean percentage of no-responses on the counterexample-rating (M=31,44, SD=24.54) and the mean percentage of AC and DA acceptance. The correlation between the likelihood-rating and the proportion of inference acceptance was significantly larger for AC than for DA (R(AC,L(p|q))=.826, R(DA, L(p|q))=.620, both N=43, $p<.05$). This can already be a first indication that the heuristic process is less important for solving DA than it is for solving AC. There is no difference in the correlation between the counterexample-rating and the percentage of AC and DA acceptance (R(AC, alt)=.746, R(DA, alt)=.625).

In order to determine the relative importance of both processes, a separate regression analysis for AC and DA will be conducted. The mean results of the likelihood-rating and counterexample-rating are entered as predictors for the proportion of inference acceptance. Because there are only two predictors, a classical MRA can be used to determine the relative contribution of both information types. The proportion of inference acceptance is transformed into logit(p) to prevent the prediction of an invalid proportion (p>1 or p<0). The results of the regression analysis are presented in Table 2.

Table 2: Results of the multiple regression analysis.

AC	R^2=.66		(N=42)
	<u>ß</u>	<u>t(39)</u>	<u>p</u>
L(p|q)	.632	3.626	<.001
Alternatives?	.203	1.162	.252
DA	R^2=.41		(N=43)
	<u>ß</u>	<u>t(40)</u>	<u>p</u>
L(p|q)	.251	1.112	.273
Alternatives?	.417	1.846	.072

For AC we found that only the likelihood-predictor accounted for a significant part of observed variance in inference acceptance. This implies that the main process for solving AC takes likelihood information into account; thus AC is mainly solved heuristically. For DA we found that only the counterexample rating accounted for a marginally significant proportion of variance. The retrieval of alternative causes seems to be the dominant process for solving DA problems. However, this analytical predictor is only marginally significant, so other factors may also be important in describing how DA is solved.

We found converging evidence in the results of a verbal protocol-study (Verschueren, Schaeken, & d'Ydewalle, 2003b). In this task participants were presented with a reasoning problem and asked to give whatever information they think is relevant (free production task). For DA there were slightly more trials in which participants referred to a counterexample to sustain their answer than for AC (.61 vs. .55). According to the specified dual process account, the explicit use of counterexample information indicates that participants used an analytic reasoning mechanism. This observation sustains our claim that DA is solved more analytically than AC.

The results indicate that the relative importance of the heuristic and analytic process is different for AC than for DA; AC is mainly solved heuristically by using likelihood-information whereas DA is rather solved analytically by using information about alternative causes. The adverb mainly indicates that <u>most</u> participants use this reasoning strategy <u>most</u> of the time. We do not exclude the possibility that some participants sometimes solve AC analytically or solve DA heuristically or that other factors intervene.

Discussion

There are a number of experimental findings and theoretical assumptions that can be linked to the present results. The characteristics of the two reasoning mechanisms have implications for both the processing time and processing difficulty of solving AC and DA. The heuristic process yields fast results and poses a minimal load on processing capacity, whereas the analytic reasoning mechanism needs more time to attain a conclusion and requires a considerable amount of processing resources.

Some differences in processing time and difficulty can also be accounted for within one of the two reasoning processes. The minimalist specification of the heuristic process is not suited to make precise predictions regarding the differences in the reasoning process of AC and DA. Oaksford, et al., (2000) explicitly refrain from speculating on how AC and DA are actually solved. From the perspective of mental model theory the processing differences between AC and DA have already been addressed. The effects on processing speed and processing difficulty are discussed separately. In this discussion we will first sketch the explanations that have been proposed by mental model theorists and subsequently frame the observed effects in the dual process specification.

Reaction time

First, it is found that the mean reaction time for solving DA is higher than the reaction time for solving AC (see e.g. Barrouillet, et al, 2000). Classically, this is explained by referring to the fact that for DA reasoners need to process a negation, which is time-consuming.

The negation-hypothesis is indeed a valuable explanation, but the present findings deliver a second possible explanation. Both reasoning mechanisms can be distinguished on a temporal dimension. Verschueren, Schaeken, & d'Ydewalle (2003c) found that for fast trials the likelihood-predictor is the only predictor accounting for a significant proportion of the observed variance. For trials in which inferences are solved rather slowly, the counterexample-predictor is the only factor accounting for a significant proportion of variance in acceptance ratings. The present data indicate that AC is solved mainly heuristically, which implies that due to the characteristics of the reasoning mechanism mainly used for solving AC, the AC conclusion is attained relatively fast. The DA conclusion is attained in a rather analytical way, this analytical reasoning mechanism takes more time to attain a conclusion, and hence in general, solving DA will take more time. Another explanation for the difference in reaction time between AC and DA can thus be found in the temporal characteristics of the reasoning mechanisms mainly used for solving AC and DA.

Processing difficulty

Second, the difference in processing difficulty between AC and DA will be discussed. According to the mental model theory AC and DA differ in a number of aspects.

A first aspect is that AC is a backward inference; DA is a forward inference. It is found that forward inferences are easier to solve than backward inferences (see Barrouillet, et al., 2000). Second, it is assumed that denial inferences (inferences containing a negation in their categorical premise) are more difficult than affirmation inferences (Barrouillet, et al., 2000). When MP and MT are included in the comparisons, the differences forward/backward and affirmation/denial are indeed very clear.

There is still a third reason for expecting a difference in difficulty between AC and DA. One of the basic principles of mental models theory is that the processing difficulty increases when reasoners have to take more models into account for solving the inference. For solving DA, reasoners need to take an extra model into account compared to when they are solving AC (Markovits & Barrouillet, 2002; see also Schroyens, Schaeken, & d'Ydewalle, 2002). Due to the necessity of manipulating the extra model 'not p, not q' to solve DA, it is expected that within the analytical reasoning mechanism solving DA is more demanding than solving AC.

Fourth, the kernel of the analytical process resides in the retrieval of counterexamples. Concerning the ease of retrieval, there are two additional differences between AC and DA. On the hand, because the premises of DA contain the explicit propositions of an alternative cause, it can be easier to find an alternative cause in case of DA than in case of AC. The automatic retrieval process of alternative causes 'not p and q' operates on the conditional premise and uses the categorical premise as an additional retrieval cue (Markovits & Barrouillet, 2000). Because these two premises of DA contain the explicit propositions 'not p' as well as 'q', we suggest that retrieving an alternative ('not p, q') is easier for DA than for AC, where only affirmative propositions are present. When AC and DA are based on causal rules, the temporal order between 'cause' and 'effect' can also motivate a preferred directionality, which could favor the retrieval process in case of DA. On the other hand, it is recently found that the same retrieval process depends on working memory capacity (see e.g., De Neys, et al, 2003; Verschueren, et al, 2002). When reasoners are solving DA they have to maintain an extra model in their working memory (the complementary 'not p, not q'-model), this can cause an extra load on working memory, which in turn burdens the efficient retrieval of alternative causes. In conclusion, there can be differences in the ease of counterexample retrieval between AC and DA, but at present we are unable to pinpoint the exact difference in the ease of retrieval of counterexamples.

This quest for finding the crucial difference in processing needs between AC and DA has not yet yielded a satisfying result. The present results deliver a valuable contribution for explaining the observed differences in processing speed and difficulty. From the general level of dual process theories, it is found that AC is mainly solved heuristically whereas DA is solved mainly analytically. So regarding the difference in processing difficulty, the dual process approach reveals that AC is mainly solved by use of a less demanding reasoning mechanism than DA is.

Conclusion

The present experiment based on the specified dual process approach shows that AC should be solved faster and should be easier to solve than DA. This is because AC is solved heuristically, which poses only minor demands on the cognitive processing resources. DA is solved mainly analytically, which implies a slower and more demanding reasoning mechanism. On a more specific level, when we look within one reasoning mechanism, e.g., the analytical reasoning process, important differences in processing time and difficulty can be revealed. However, when this specific reasoning mechanism is the subdominant reasoning strategy for some inferences, as it is for AC, we have to be careful in using a single reasoning mechanism to explain observed processing differences.

The general dual process theories are not well suited to formulate precise experimental predictions, but they deliver a valuable framework for specifying concrete reasoning mechanisms. This implies that there are two conceptually different levels of explaining experimental observations. Either researchers confine themselves to one reasoning mechanism to frame experimental findings, for instance the mental model theory. Or one considers a broader perspective on reasoning, being a dual process account, which can give rise to alternative explanations for observed differences.

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