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The interpretation of the concepts 'necessity' and 'sufficiency' in forward unicausal relations

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5   Our understanding of causal relations is so much a part of our daily lives that it is often forgotten that the fundamentals of this ability are not yet fully understood. One of the central findings regarding the human causal inference process is that the necessity and/or sufficiency of the cause assume a central role in the inference process (Cummins, 1995; Markovits & Barrouillet, 2002; Thompson, 1994; 2000). We will investigate how people understand and assess these central properties, i.e. the necessity and sufficiency of a cause for the effect.

6   In daily life there is a mass variety on causal scenario's with differing complexity, e.g., finding the cause(s) of a mental illnesses, understanding the determinants of partner choice, pinpointing the cause of a car accident or a certain disease etc. The basic unit of a causal scenario is an 'if cause, then effect' link. In this article we confine the research to forward unicausal conditionals where one cause is linked to one effect. Many studies revealed that there is a robust relation between the perceived necessity and sufficiency of the cause and the conclusions that reasoners draw from simple 'if cause, then effect' conditionals. This perceived sufficiency and necessity (as perceived by the reasoner) is conventionally equalled to the theoretical sufficiency and necessity as determined by the researcher. It is however not yet clear whether the formal definitions of necessity and sufficiency reflect the way reasoners use and interpret these concepts. Brennan (2003)

already concluded that 'there is a need for caution when we move from natural language conditionals to analysis in terms of necessary and sufficient conditions' (p. 9). Despite this underdeterminacy it is often argued that how people interpret the necessity expressed by a conditional relation has a causal impact on the number and types of inferences that are drawn (Thompson & Mann, 1995). By describing how people define and use the concepts of necessity and sufficiency it can be clarified whether the levels of necessity and sufficiency as perceived by the experimenter converge with the ordinary, lay-people's perception of necessity and sufficiency.

7   In logic, one proposition is a necessary condition of another when the second cannot be true while the first is false, and one proposition is a sufficient condition for another when the first cannot be true while the second is false. Alternatively formulated: A is a necessary condition for B if and only if it is never the case that B occurs and A does not occur, A is a sufficient condition for B if and only if it is never the case that A occurs and B does not occur (Facione, 1972).

8   Research on conditional reasoning revealed that logical conceptions and definitions are not necessarily psychologically relevant or valid. In most situations people take information about the context as well as their background knowledge into account (for an overview, see Politzer & Bourmaud, 2002). This renders logical assertions inapplicable. According to logic one should base inferences solely on the content of the premises that are categorically assumed true. Nonetheless, the definitions used by reasoning researchers are generally comparable to the formal definitions[1] Table 1 provides an overview of how reasoning researchers define the concepts of sufficiency and necessity. Because the *perceived* levels of necessity and sufficiency are often used as predictors of reasoning performance, it is important to investigate how these concepts are understood. We will conduct three experiments that enable us to gain perspective on how people understand the sufficiency and necessity in forward unicausal relations.

Table 1: Indications/definitions for necessity and sufficiency used by different reasoning researchers

Indication/Definition	Used by
Sufficiency	
If the cause occurs, the effect always follows/must follow.	Fairley, Manktelow, & Over (1999) Bindra, Clarke, & Schultz (1980) Thompson (1994) O'Brien & Davidson (1989)
If the effect does not occur, the cause did not precede.	Fairley, et al. (1999)
Necessity	
If the effect occurs, the cause must have preceded	Fairley, et al. (1999) Thompson (1994) O'Brien & Davidson (1989)
If the cause is absent, the effect cannot take place	Fairley, et al. (1999) Bindra, et al. (1980)

Experiment 1

9   What do people consider as necessary and sufficient conditions to conclude that the cause is necessary or sufficient for the effect? A first step is to see how people define the two concepts. In Experiment 1 participants are asked to give their own definition of (non)-necessity and (non)-sufficiency in a written free response format. To check the face-validity of two formal definitions of necessity and sufficiency the answers were interpreted in terms of the listed co-occurrences of cause and effect.

10   The two formal indications for sufficiency and necessity are

11   For sufficiency:

12   1. If the cause occurs, the effect always follows/must follow.

13   2. If the effect did not occur, the cause did not precede.

14   For necessity:

15   1. If the effect occurs, the cause must have preceded.

16   2. If the cause is absent, the effect cannot take place

17   There are two principles that can cause one indication to be preferred over the other.

18   The first is the principle of *causal priority* (see e.g., Waldmann & Hagmayer, 2001). This principle entails that causes ontologically precede their effects and not the other way around. Given this regularity, it would be easier to think, reason and evaluate causal relations in a forward than in a backward direction. The first indication of sufficiency and the second indication of necessity are forward formulations, the other two are backward formulations.

19   The second factor is the *polarity* of the formulation. It has already extensively been shown that a premise containing a negation is harder to reason with than an affirmative premise

(Schroyens, Schaeken, & d'Ydewalle, 2001; Schroyens, Verschueren, Schaeken, & d'Ydewalle, 2000). The first indications of sufficiency and of necessity contain only affirmative propositions, while the second indications contain negated propositions.

20 For sufficiency, the two facilitating factors co-occur in the first formulation, for necessity one formulation favours directionality, the other favours polarity. Based on the free-response data the occurrence of both types of formulations will be verified as well as the complexity of the given definitions and paraphrases.

MethodParticipants

21 The experiment was run with twenty-seven first year psychology students. The students of this and the following experiments were all native speakers who participated in partial fulfilment of course requirements. None of them received training in formal logic.

Design and Procedure

22 Each participant received a paper with the following instructions and questions:

23 Recent research on reasoning with causality revealed the importance of the concepts necessity and sufficiency in human reasoning. Because these two concepts are rather abstract and difficult to define, you are asked to write down your own definition of necessity and sufficiency. Try to be complete and precise in your formulation (paraphrase, circumscribe, what are the preconditions...).

24 The cause is necessary for the effect, what does this mean to you?

25 The cause is not necessary for the effect, what does this mean to you?

26 The cause is sufficient for the effect, what does this mean to you?

27 The cause is not sufficient for the effect, what does this mean to you?

28 Below each question the participants could write a few sentences. Participants were given ten minutes to complete the task. Every participant was able to complete the task within this given time frame.

Results and Discussion

29 The answers were transcribed to highlight the different cause-effect combinations that participants mentioned for defining necessity and sufficiency. We verified in which direction cause and effect were linked and whether the propositions were negated or affirmative. Table 2 provides an overview of the different cause-effect combinations that were found in the answers.

Necessity and sufficiencyDirection versus Polarity

30 The four sufficiency/necessity indications corresponding to the formal definitions occurred in 50 of the 54 answers (93%). To verify whether there was any preference in the two formulations, the range of answers was narrowed down to the cases where participants listed only one combination of cause and effect.

31 First, the polarity factor was checked: the number of times the affirmative formulations were used was compared to the number of times the negative formulations were used. For sufficiency, 24 of the 27 definitions (89%) consisted of the singular expression: 'if the cause is present, the effect will follow'. One participant wrongly reversed this formulation 'if effect, then cause' which points to necessity instead of sufficiency. The complementary formulation 'if there is no effect, the cause did not occur' was not observed. This can be linked to the fact that people do not always accept the logical (not necessarily psychological) equivalence between the conditional (if cause then effect) and its contrapositive (if no effect then no cause; see e.g., Pollard & Evans, 1980). For necessity,

15 out of 27 participants (56%) used the formulation 'if the cause is absent, the effect cannot follow' whereas 4 out of 27 participants (15%) listed that 'if the effect occurs, the cause preceded'. The polarity preference is thus observed for sufficiency but not for necessity.

32   Second, the effect of directionality was checked. Both dimensions were preferably defined by the forward description (93% for sufficiency, 74% for necessity) rather than by the backward description (4 % for sufficiency, 15% for necessity). The preference for forward formulations appears to be stronger for sufficiency than for necessity. Presumably because for sufficiency both facilitating factors (direction and polarity) are combined, while for necessity the affirmative formulation goes from effect to cause. The observation that participants used the forward but negative necessity formulation 15 times (56%) and only used the backward yet affirmative formulation 4 times (15%) might suggest that the direction of the model is more important than the polarity of the propositions contained in the model.

Necessary and sufficient

33   A special case of causal relation is when the cause is both sufficient and necessary for the effect, cause and effect are then exclusively related to each other. We found some definitions of necessity and sufficiency that expressed his kind of equivalence relation. The equivalence combination was 'cause, thus effect' (indication of sufficiency) with 'no cause, thus no effect' (indication of necessity). For necessity there were 5 definitions (18,5%) where the cause was considered necessary as well as sufficient, for sufficiency there were none. This suggests that at least for some people the necessity of the cause is a stronger warrant to full equivalence than the mere sufficiency of the cause. This is in accordance with O'Brien and Davidson (1989), they observed that people treat a mere necessary relation more frequently as a necessary and sufficient relation than a mere sufficient relation. This asymmetric tendency towards equivalence can be linked to the finding that relations that are necessary are considered as more causal than relations that are mere sufficient (Siegler, 1976).

Complexity

34   O'Brien and Davidson (1989) stated that the sufficiency of a relation could be established by fewer instances than the necessity of a relation. To get an indication of the subjective *complexity* of sufficiency and necessity, we looked at the number of situations (models) that are present in each description. For sufficiency, there were 25 single model formulations {96.2%) and 1 dual model, for necessity there were 19 single models formulations (70.4%) and 8 dual model formulations. For non-sufficiency there were 58.2% of single model formulations while there were only 36% for non-necessity. Taken together these results reveal that the necessity dimension is subjectively more complex than the sufficiency dimension.

35   The answers of the participants contained information beyond what is presented in Table 2: For sufficiency 5 (out of 27) participants had a graded, more liberal interpretation, e.g., 'there is some sort of threshold for attaining the effect' or 'the cause has to be present to some extent in order to bring along the effect' and one definition of sufficiency could not be linked to a cause-effect combination: 'the cause can be enough to warrant a conclusion'[2].

Table 2: **Number of participants that included the following models in their definitions of necessity, sufficiency, non-necessity and non-sufficiency**

	Forward			Backward	Mixed
	C _ E	No C _ No E	C _ E No C _ No E	E _ C	E _ C No C _ No E
Sufficient	24	0	1	1	0
Necessary	0	15	5	4	3

	Forward				Backward		Mixed
	No C _ E C _ No E	C _ E C _ No E	C _ No E	C _ E No C _ E	E _ No C	E _ C E _ No E	C _ No E No E _ No C
Not Sufficient	1	0	22	0	0	0	4
Not Necessary	1	2	2	10	6	4	0

Non-sufficiency and non-necessity

36 The definitions of non-sufficiency and non-necessity of Table 2 were compared to the definitions of sufficiency and necessity. Most definitions of non-sufficiency and non-necessity are modified versions of the definitions of sufficiency and necessity. The dominant indication for sufficiency 'cause, thus effect' was given by 24 subjects (89%). The denial of this proposition is 'cause, thus no effect', this indication for non-sufficiency was given by 22 subjects (81.5%). Four other participants (14.8) used this denied indication in combination with a 'no effect, thus no cause' indication. The definitions of non-sufficiency are thus strongly related to the definitions of sufficiency.

37 The dominant indication for necessity was 'no cause, thus no effect' (55.6%). This formulation contains two negated propositions. In order to deny a negated proposition, people have to solve a double negation, which imposes a severe cognitive load (see e.g. Schroyens et al., 2001). Not surprisingly, for defining non-necessity the denied form of the dominant indication 'no cause, thus effect' was only mentioned by one subject (3,7%). The second dominant indication of necessity (18,5%) consisted of two models: 'no cause, thus no effect' and 'cause, thus effect'. For non-necessity, ten participants (37%) repeated this first model and denied the second model into 'no cause, thus effect'. For non-necessity the denied, single model version 'effect, thus no cause' was given by 6 participants (22,2%).

38 Some responses revealed that the link cause-effect in non-necessary relations is indeterminate: Two participants (7,4%) stated that the effect may or may not follow the cause and four participants (14,8) stated that the cause may or may not precede the effect.

39 For describing non-sufficiency 23 (85,2) participants used a single model, while four (14,8) used two models. For describing non-necessity, nine (33.3%) participants used a single model, while sixteen used two models. This converges with our previous findings on the

contrast sufficiency-necessity: The necessity-dimension is more complex than the sufficiency dimension.

Summary

40   There were a considerable number of answers that are congruent with the formal definition. The results revealed that participants are more inclined to define sufficiency and necessity by using a forward formulation rather than by a backward formulation, this can be linked to the causal priority principle. The data also showed that the representation of the dimension of necessity is more complex than the representation of sufficiency. The indications of non-sufficiency and non-necessity are often the denied version of sufficiency and necessity, respectively. Whereas necessity is stronger linked to equivalence than sufficiency, non-necessity is stronger linked to indeterminacy than non-sufficiency.

41   Now that we have some grasp on how participants define the concepts of necessity and sufficiency, we will ask them in Experiment 2 to rate the necessity and sufficiency of the cause for different causal situations. This will inform us on how the two concepts are actually used.

Experiment 2

42   Whereas the previous experiment focussed on the definition of the concepts of necessity and sufficiency, we will now test how participants assess the sufficiency or necessity of different situations. In order to explore people's assessment behaviour we constructed nine possible unicausal relations by systematically varying the likelihood of the effect (follows always/maybe/never) for situations where the cause is either present or absent. Table 3 displays the nine resulting relations, the schematic representation of the relation is based on Edgington (1995, p. 262). For each of the relations, the following four questions were asked:

43   Is the cause sufficient for the effect? yes/no

44   Is the cause necessary for the effect? yes/no

45   Can the cause occur without the effect following? yes/no

46   Can the effect occur without the cause preceding? yes/no

47   Question 1 and 2 are called literal formulations; the participants are asked whether the cause is sufficient or necessary without further explanation/explication. Questions 3 and 4 are called guided questions, these questions compel subjects to verify two conditions that are diagnostic for the necessity and sufficiency of the cause (both affirmative formulations). For the two literal questions, we scored the 'yes' answers as 1, for the two guided questions the 'no' answers were scored as 1. The two guided questions were included to see whether participants can extract the minimal information needed to answer the literal questions 1 and 2. The comprehension of a certain causal relation is not necessarily an all-or-none affair. Participants may be able to verify a certain relation when put in concrete wordings, without having the ability to comprehend the more complex or formal description (Bindra, Clarke, Schultz,1980).

Method

48   Eighty-nine first year psychology students participated in the experiment. The cover story read that scientists were sent to newly discovered planets in order to investigate some extraordinary physical phenomena. Participants were informed about the causal relation the scientists expected to observe (causal conditional) and about the scientists' actual observations concerning this causal relation (factual causal relation). Next, they

were asked to evaluate this factual causal relation. The cause and effect propositions were replaced by content-lean propositions to form a novel (arbitrary) causal relation, the 9 novel causal relations can be found in the Appendix. This was done to minimise the effect of background knowledge; participants could only rely on the presented relations to infer the necessity and sufficiency. The task looked as follows (translated from Dutch):

49 On the planet Bur you can find a sticky green substance. Scientists assume that:

50 If the sticky green substance is heated, then it turns lightly pink.

51 Extensive observation revealed the factual relation between 'heating the green substance' and ' turning pink'. This factual relation can be summarised as follows. Note that all situations that are relevant for the relation between cause and effect are examined.

Green substance is heated	Substance turns pink
Green substance is not heated	Substance turns pink OR Substance does not turn pink

52 Is heating the green substance sufficient for it turning pink? yes/no

53 Is heating the green substance necessary for it turning pink? yes/no

54 Can the substance be heated without this substance turning pink? yes/no

55 Can the substance turn pink without the substance being heated? yes/no

56 The instructions made clear that the left column referred to the two mutually exclusive possible antecedent conditions and the corresponding row of the right column informed them on the respective consequent possibilities. All participants received the nine possible situations (see Table 3). Each situation was presented on a separate sheet and the order of the nine situations was counterbalanced. For each depicted causal relation participants were asked to answer the four questions about necessity and sufficiency. In addition, they were asked to solve one of four conditional inferences (MP, MT, AC, and DA) for each presented relation. The results of the reasoning task are discussed in Verschueren, Schroyens, Schaeken, and d'Ydewalle (2004). The table depicting the relation remained visible for the participants when they answered the four questions and the reasoning problem.

Table 3: Schematic representation of the 9 situations used in Experiment 3 (reference number between square brackets).

9 SITUATIONS	No Cause	Effect	No Cause	No Effect	No Cause	Effect / No Effect
Cause Effect	Cause	Effect	Cause	Effect	Cause	Effect
	No Cause	Effect	No Cause	No Effect	No Cause	Effect
	[1]		[2]		[3]	No Effect
Cause No Effect	Cause	No Effect	Cause	No Effect	Cause	No Effect
	No Cause	Effect	No Cause	No Effect	No Cause	Effect
	[4]		[5]		[6]	No Effect
Cause Effect No Effect	Cause	Effect	Cause	Effect	Cause	Effect
		No Effect		No Effect		No Effect
	No Cause	Effect	No Cause	No Effect	No Cause	Effect
	[7]		[8]		[9]	No Effect

Results and discussionInterpretation of sufficiency and necessity

57 Figure 1 displays the mean ratings for sufficiency and necessity, for the literal and guided formulation as well as the criterion score that is expected when the formal definition(s) are applied. The criterion necessity score for situation 5 is undetermined: If the effect never occurs it is impossible to derive the necessity of the cause for this effect.

Figure 1. Experiment 2: Mean score of sufficiency and necessity on the guided and the literal questions, compared with the criterion score for each of the nine situations.
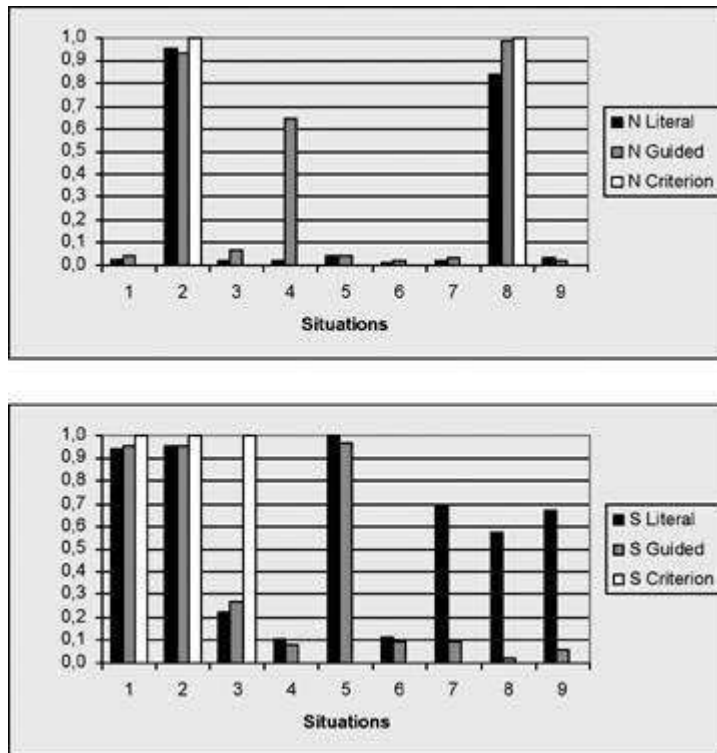
Literal versus guided formulation

58   First, the literal and the guided formulation will be compared in order to discover certain misconceptions. A Kruskal-Wallis ANOVA by ranks indicated that for all four ratings there was a significant effect of the situation type, for necessity /literal*: $H(8, N=782)$ = 602.6, *p* < .001; for sufficiency/literal: *$H(8, N = 782)$ = 367, *p* < .001; for necessity/guided: *$H(8, 782)$ =573.75, *p* < .001; for sufficiency/guided: *$H(8, 782)$ = 543.17, *p* < .001. Next, we discuss specific contrasts for the four situations where the literal and the guided formulation differed.

59   Most surprising was that the situations 7, 8, and 9 received a significantly higher rating for sufficiency in the literal formulation than in the guided formulation. For situation 7: *Wilcoxon T* = 119, *N non-ties* = 33, *p* < .005 ($M_{literal}$ = .697, M_{guided} = .090), for situation 8: *T* = 41, *N* = 40, *p* < .001 ($M_{literal}$ = .573, M_{guided} = .022) and for situation 9: *T* = 66, *N* = 32, *p* < .001 ($M_{literal}$ = .674, M_{guided} = .056). In all three situations the cause could both be followed by the effect and not followed by the effect. The observation that a majority of participants considered the cause sufficient even when the effect did not always follow possibly indicates that participants do not follow the logical definition of sufficiency. The subjective conception of sufficiency is more liberal than the formal conception. This converges with our previous observations: The results of Experiment 1 showed that 18% of the participants used a formulation indicating a graded property for the sufficiency definition.

60   For necessity, the situation that yielded a significant difference between the literal and the guided rating was situation 4. The cause depicted in situation 4 received a higher rating for necessity in the guided formulation than in the literal formulation, *T* = 86, *N* = 85, *p* < .001 ($M_{literal}$ = .023, M_{guided} = .648). This relation consisted of two models: 'cause - no

effect' and 'no cause – effect', the reverse relation of an equivalence relation. This is an odd relation; the cause prevents instead of causes the effect. On the guided question 'can the effect occur without the cause' participants should answer 'yes' (low necessity). The surprisingly high necessity scores may reflect confusion or misreading.

Subjective versus objective sufficiency and necessity

61　When we compared the scores given by participants with the criterion score that is expected based on the formal definition, we see that for sufficiency situation 3 received a lower score than expected, whereas situation 5 received a higher score. The relation of situation 5 shows that the effect never occurs, regardless of the presence of the cause. It is quite surprising that for this situation almost all participants label the cause as sufficient. A possible reason might be that participants have misread the given situation as 'cause-effect and no cause-no effect', which corresponds to a prototypical causal relation. The lower score for sufficiency on situation 3 converges with previous findings. Verschueren et al. (2004) report an experiment with a different setup, they found that the subjective sufficiency ratings of a sufficient but not necessary cause are significantly lower than the sufficiency ratings for a relation where the cause is both sufficient and necessary. They explained this result by referring to the complexity of the relation; a sufficient but not necessary relation is more complex to represent than a sufficient and necessary relation. A similar line of reasoning can be followed here: There is no a priori reason to expect a drop in sufficiency, both situation 1 and situation 2 received a high sufficiency rating, showing that the 'no cause – effect' as well as the 'no cause – no effect' model are possible when the cause is sufficient. The only difference is that for situation three, there are three models to be integrated instead of two and there is no simple way of summarising the relation. This increased complexity can by itself lead to an increased uncertainty or a misunderstanding.

62　The obtained ratings for situation 5 and to some extent also situation 4 and 6 suggest that participants have trouble grasping the meaning of these causal relations. There are many different ways in which a conditional can be interpreted. Johnson-Laird and Byrne (2002) list twelve possible interpretations that people may attain by semantic and pragmatic modulation of a given conditional formulation. The situations 4, 5 and 6 do not correspond to any of the twelve conditional interpretations listed by Johnson-Laird. It is thus possible that participants fail to answer some of the questions about necessity and sufficiency because they have trouble representing the given relation. If this confusion has arisen because of the phrasing as a causal conditional, presenting the same information without a conditional embedding may bypass the problem.

Conditions to conclude that a cause is sufficient/necessary.

63　In this paragraph we will investigate whether participants rely on one of the two formal indications, or both, to assess the sufficiency and necessity of a given cause. For sufficiency, the two indications were (a: affirmative) when the cause occurs the effect follows and (b: negative) the absence of the effect implies the absence of the cause. Situation 1 in Table 3 contains only the affirmative formulation while situations 2 and 3 also contain the negative formulation. There are no significant differences in the rating of sufficiency between both situations (chi^2 = 1.33 for situation 1 vs. 3; chi^2 = 0 for situation 2 vs. 3). It seems that the affirmative sufficiency- model is enough to grant the conclusion that the cause is sufficient for the effect. The addition of a negative sufficiency model does not increase the perceived sufficiency. Whether the negative sufficiency-model is sufficient by itself cannot be tested with the present design.

64 A cause is necessary for the effect when (a: affirmative) the occurrence of the effect implies the occurrence of the cause and (b: negative) the absence of the cause implies the absence of the effect. The relation depicted by situation 5 contains only the situation model corresponding to the forward (negative) formulation of necessity, while situation 2 and 8 contain both the forward and the backward formulation of necessity. Experiment 1 showed that participants preferred the forward formulation to define necessity. The Mac Nemar Change test revealed that the negative situational model 'no cause thus no effect' is by itself insufficient to consider the cause a necessary condition for the effect (chi^2 = 80.01, p < .001 for diagram 5 vs. 2; chi^2 = 70.01, p < .001 for diagram 5 vs. 8). Participants only inferred that the cause was necessary when the diagram revealed that the cause always preceded the effect. This shows that participants are not inclined to verify the negative version of necessity or that they consider this negative relation by itself insufficient to conclude that the cause is necessary for the effect. The present data do not inform us about whether the affirmative necessity-model is sufficient to trigger a necessity conclusion.

Summary

65 We conclude that participants have a fairly accurate understanding of necessity (with exception of situation 4), but that they do not understand what sufficiency logically entails. The comparison between the literal and the guided formulation make clear that their spontaneous, subjective understanding of sufficiency leads to a different information extraction than the one suggested by the formal, guided question.

66 It is found that the affirmative and forward model is sufficient to conclude that a cause is sufficient. This converges nicely with the preference of defining sufficiency by use of the forward formulation found in Experiment 1. For necessity, both definitions have their value, although the preferred negative and forward model is insufficient to conclude that a cause is necessary.

Experiment 3

67 In Experiment 2 it was found that for situations where the cause may or may not be followed by the effect (situations 7, 8, and 9) the majority of the participants consider the cause as sufficient for the effect. This is a surprising observation that will be tested further in Experiment 3. We will use a truth-table format to verify whether participants consider the combination 'cause and no effect' a valid possibility when they are told that the cause is sufficient to produce the effect. Truth-table research is classically used to investigate how a certain relation is interpreted and represented (see e.g. Newstead, Evans, & Byrne, 1993). In this task participants are confronted with an 'if cause, then effect'- statement and are asked to evaluate the four possible combinations of presence/ absence of cause and effect.

68 In Experiment 1 we found that some participants do not define sufficiency as an all-or-non-property but rather as a graded property. In Experiment 2 the majority of the participants considered the cause of a relation where the effect may or may not follow as sufficient for the effect. If indeed sufficiency does not have a determinate, stringent structure we expect that some participants allow the combination 'cause and no effect' and still consider the cause as sufficient.

Method

69 Twenty-eight students took part in the study. They were all tested at the same time. For each of the four combinations of cause and effect, participants were asked to indicate

whether the combination was possible for a sufficient/necessary cause. Figure 2 gives an example of the task, including the responses we should observe when participants rely on the formal definitions. The definition of sufficiency does not relate to the third combination, the definition of necessity does not relate to the fourth combination, both are possible but not necessarily present. When participants have indeed a more liberal interpretation of sufficiency, we expect that the 'cause – no effect' combination is considered as possible in a significant proportion of trials. When a reasoner considers a certain combination possible, the answer is scored as 1; when it is considered impossible it is scored as 0.

Figure 2. **Truth-table task for investigating the necessity and sufficiency interpretation**

The cause is sufficient for the effect		
Combinations	Possible	Impossible
1. Cause occurs – Effect occurs	x	
2. Cause occurs – No effect		x
3. No Cause – Effect occurs		
4. No Cause – No effect	x	

The cause is necessary for the effect		
Combinations	Possible	Impossible
1. Cause occurs – Effect occurs	x	
2. Cause occurs – No effect		
3. No Cause – Effect occurs		x
4. No Cause – No effect	x	

Results and discussion

Table 4: **Percentage of trials in which the combinations are considered possible, standard deviations are given between brackets (N =28).**

	Cause - Effect	Cause – No Effect	No Cause - Effect	No Cause – No Effect
Sufficient	100 (0)	60.7 (49.7)	46.4 (50.7)	85.7 (35.6)
Necessary	96.4 (18.9)	57.1 (50.4)	14.3 (85.6)	92.9 (26.2)

70   Table 4 displays the percentage of possible-answers. First, for sufficiency the two combinations corresponding to the formal definitions were more often considered as possible than the two other combinations. The 'cause – effect' combination received a 100% score, the 'no cause – no effect' combination for sufficiency was considered possible in 85.7%. There was a marginally significant difference between these two formal indicators ($T = 0$, $Z = 1.826$, $n = 4$, $p = .068$). This finding underscores the findings of Experiment 1: people consider the 'no cause – no effect' combination by itself not as a valid indication for sufficiency. The formally illegal combination 'cause - no effect' scored significantly lower (60.7%) than the two formal combinations (C noE vs CE: *Wilcoxon T* = 0, $Z = 2.934$, *n non-ties* = 11, $p < .05$; C noE vs. noC noE: $T = 5$, $Z = 2.073$, $n = 9$, $p < .05$). Despite that the 'no cause – effect' combination should be considered possible, we observe that this combination (that may or may not occur) receives a significantly lower score than

the two formal combinations that have to occur (noC E vs. CE: $T = 0$, $Z = 3.408$, $n = 15$, $p = <.01$; noC vs. noC no E: $T = 0$, $Z = 2.343$, $n = 27$, $p = <.05$). Surprisingly, the formally illegal 'cause, no effect' combination did not differ significantly from the formally possible but not necessary 'no cause - effect' combination. (46.4%; $T = 26$, $Z = 1.020$, $n = 12$, $p = .3078$). The formally illegal 'cause – no effect' combination was considered possible in 61% whereas the 'no cause – effect' combination was considered possible only in 46% percent of the cases. This observation converges with the findings of Experiment 1 and 2. We conclude that (some) participants understand sufficiency in an indeterminate way, allowing that the effect may not follow the cause.

71 Second, we consider the results for necessity. According to the formal conceptualisation of necessity the 'no cause – effect' combination is illegal, whereas the combination 'cause – no effect' is possible but not necessary. The two formally legal combinations 'cause - effect' and 'no cause - no effect' received high scores and did no differ significantly (96.4% and 92.9% respectively; $p = .592$). The formally illegal 'no cause - effect' combination received a significantly lower score (14.3%; noC E vs. CE: $T = 13$, $Z = 4.023$, $n = 25$, $p <.01$; noC E vs. noC no E: $T = 0$, $Z = 4.106$, $n = 22$, $p <.01$). According to the formal definition, the combination 'cause - no effect' may or may not occur and should thus be considered as possible, 57.1% of the participants considered this combination possible. This is a significantly lower score than the two combinations that are always true (C noE vs. CE: $T = 0$, $Z = 2.934$, $n = 11$, $p <.01$; C noE vs. noC noE: $T = 15$, $Z = 2.354$, $n = 14$, $p <.05$) but it received a significantly higher score than the formally illegal 'no cause, effect' combination ($T = 28.5$, $Z = 2.484$, n = 18, $p <.05$).

72 When we look at the patterns of relevant combinations for a sufficient cause, there were 8 participants who considered the 'cause – effect', 'cause – no effect' and the 'no cause – no effect' combinations respectively possible, impossible and possible (29%), whereas there were 16 participants who found all three combinations possible (57%). The alternative, more liberal interpretation of sufficiency occurs thus more often than the formal interpretation. For necessity, there were 22 participants that considered the 'cause-effect', 'no cause-effect' and 'no cause- no effect' respectively possible, impossible and possible (79%), whereas only 3 participants considered all three combinations possible (11%). The 'no cause –effect' combination is thus understood as a combination that contradicts necessity.

Summary

73 The results from Experiment 3 confirm the findings from Experiment 1 and 2. The majority of participants interpret sufficiency as a graded property whereas necessity keeps its all-or-none status. About six out of ten participants considered 'cause and no effect' a possible combination for a sufficient cause. When a cause is necessary for an effect, the 'no cause – effect' combination is not accepted.

General discussion

74 The current research highlights the importance of distinguishing the subjective definition of necessity and sufficiency from their formal definitions. Although the subjective conceptualisation of necessity parallels the formal definition; the subjective concept of sufficiency is different, less stringent than the formal concept. The current finding about the subjective meaning of sufficiency can be related to some recent findings about abstract conditional reasoning, that show that contrary to formal logic, people often think about conditionals in an indeterminate way (Evans & Over, 2003; Oberauer & Wilhelm, 2003).

75   Putting it strong, people do not use the concept of sufficiency in its logical, formal meaning. This observation can be linked to the current debate on everyday Rationality-1 and normative Rationality-2 (Evans & Over, 1996). The Rationality 2-criterion dictated by normative theories is not suited to evaluate an everyday, Rationality-1 way of thinking. Vanquickenborne (1969) already argued that because in everyday situations it is rather exceptional that the cause is always followed by the effect (sufficiency) or that the effect is always preceded by the cause (necessity), the causal relations used in everyday language are weaker than a strictly sufficient and/or necessary condition. To give an example; smoking causes lung cancer. What would be expected when asked whether smoking is a sufficient cause for lung cancer? Because most people know smokers who did not get lung cancer, smoking can formally not be considered as a sufficient condition. However, it is commonly known that smoking significantly increases the probability of getting lung cancer. This graded, positive relationship between cause and effect can be sufficient to label the cause as sufficient for the effect. Indeed, in a previous study we asked one group of participants whether the cause is sufficient/necessary for the effect. Another group was asked whether it is possible that the effect does not follow the cause (sufficient) and that the cause does not precede the effect (necessary). Surprisingly, there was a considerable number of sentences where the majority of participants said that it was possible that the cause was not followed by the effect while at the same time participants still considered the cause sufficient for the effect. For instance, for the sentence:'If you drink coffee late in the evening, then it is harder to fall asleep' there were 95% of the participants said that it was possible to drink coffee late in the evening and not making it harder to fall asleep, yet 86% of the participants said that the cause (drinking late night coffee) was sufficient to fall asleep.

76   What makes then that sufficiency is interpreted as less determinate than necessity? When we analyse the relevance and occurrence of both dimensions for everyday situations, we can suggest a possible reason. It has already been shown that the search for necessary causes is triggered in case of an undesired effect, while the search for a sufficient cause is triggered in case of a desired effect (Lewicka, 1989; 1992). In case the effect is not desired, it is important to find a way of categorically preventing this effect. If people know of a necessary precondition for the effect, the total absence of this precondition serves the purpose. However, for a desired effect it can be interesting to be merely able to augment the probability of this effect taking place. This can already reveal that it can be more adaptive to consider sufficiency in gradual terms and necessity in categorical terms.

77   An important consequence of the observed divergence between the formal and the subjective definitions is that the effect of necessity and sufficiency on conditional reasoning has to be reconsidered. It is often stated that the subjective levels of necessity and sufficiency predict the reasoning performance, but it remains yet to be tested whether it is the perceived levels of necessity and sufficiency that are reflected in the reasoning results rather than the objective levels that are manipulated by the researchers. The recent findings of Verschueren, Schroyens, Schaeken, & d'Ydewalle (2004) can provide a partial answer. They found that effects on inference acceptance rates are not always mediated by effects in the subjective necessity and sufficiency ratings. They suggest that participants do not base their inferences on their assessment of the cause as necessary and sufficient. The question then remains why the objective levels of necessity and sufficiency have such a pervasive impact on the reasoning results, even when abstract premises are used.

78   A second, related observation is that the concept of necessity is more complex than the concept of sufficiency. According to O'Brien and Davidson (1996) this is because the sufficiency of a cause can be established by fewer instances (mental models) than the necessity of a cause. Although we only considered unicausal relations, we found evidence corroborating this claim: To verify sufficiency participants verify only one (gradual) relation, whereas for necessity the criterion is more stringent (all-or-none) and consists of two indications. Each of this two indicators by itself requires more cognitive resources than the affirmative forward 'cause thus effect' indicator of sufficiency: 'effect thus cause' is backward, 'no cause thus no effect' contains a negation. We do not know whether both indicators of necessity are used to assess the status of a cause, but it was found that the recognition of the first model is insufficient to conclude that a cause is necessary. Taken together this corroborates the finding that necessity is more complex than sufficiency.

79   In sum, the subjective conceptualisations of necessity and sufficiency do not parallel the formal definitions that are used in the literature on causal reasoning. It seems to be more ecologically valid to define sufficiency in terms of for instance the likelihood that the cause brings about the effect, rather than in terms of an all-or-none property. When investigating the effect of the necessity and sufficiency of the cause on causal reasoning or decision making, researchers should stop at the thought of a valid operationalisation of these constructs. A look at how reasoners understand the central theoretical concepts can avoid theoretical aberrations.

Acknowledgements

Appendix: Different contexts used for Experiment 2

81   The names of the different planets were chosen to avoid spontaneous semantic associations (for Dutch-speaking subjects). There were nine different <u>planets</u>: Bur, Lif, Zom, Wex, Muk, Nac, Loz, Keq, and Vyb.

82   The nine novel *causal relations* were:

83   1. If you heat the green sticky substance, then it turns light pink

84   2. If the small white animals are exposed to sunlight, then they die

85   3. If you drop these pearly pebbles, then they break in two

86   4. If you drink the blue fluid, then your head starts spinning

87   5. If you pull a bright yellow leaf from this plant, then there appears a black bud

88   6. If you boil these sweet tasting fruits, then they become bitter tasting

89   7. If the purple gas adds to the red gas, then there is an explosion

90   8. If two of these orange marbles touch, then a poisonous smoke evaporates from them

91   9. If the treacly black stuff is stirred, then the stuff becomes glassy

BIBLIOGRAPHY

Barrouillet & Lecas (1999). Mental models in conditional reasoning and working memory. *Thinking and Reasoning, 5*, 289-302.

Bindra, D., Clarke, K. A., Shultz, T. R. (1980). Understanding predictive relations of necessity and sufficiency in formally equivalent 'causal' and 'logical' problems. *Journal of Experimental Psychology: General, 109*, 422-443.

Brennan, A. (2003). Necessary and sufficient conditions. *The Stanford Encyclopaedia of Philosophy (Fall 2003 Edition)*, Edward N. Zalta (Ed.), http://plato.stanford.edu/archives/fall2003/entries/necessary-sufficient/>.

Byrne, R. M. J., Espino, O., & Santamaria, C. (1999). Counterexamples and the suppression of inferences. *Journal of Memory and Language, 40*, 347-373.

Cummins, D.D. (1995) Naïve theories and causal deduction. *Memory and Cognition, 23,* 646-658.

Cummins, D. D., Lubart, T., Alksnis, O., & Rist, R. (1991). Conditional reasoning and causation. *Memory & Cognition, 19*, 274-282.

Edgington, D. (1995). On conditionals. *Mind, 104*, 235-329.

Evans, J. St. B. T., Newstead, S. E., & Byrne, R. M. J. (1993). *Human reasoning: The psychology of deduction.* Hillsdale: Erlbaum.

Evans, J. St. B. T. & Over, D. E. (1996). *Rationality and reasoning.* Hove: Psychology Press.

Facione, P. A. (1972). A modal truth-tabular interpretation for necessary and sufficient conditions. *Notre Dame Journal of Formal Logic, 13*, 270-272.

Fairley, N., Manketelow, K., & Over, D. (1999). Necessity, sufficiency, and perspective effects in causal conditional reasoning. *The Quarterly Journal of Experimental Psychology, 51,* 771-790.

Johnson-Laird, P. N. & Byrne, R. M. J. (1991). *Deduction.* Hillsdale: LEA.

Johnson-Laird, P. N. & Byrne, R. M. J. (2002). Conditionals: a theory of meaning, pragmatics, and inference. *Psychological Review, 109,* 646-678.

Johnson-Laird, P. N., Byrne, R. M. J. & Schaeken, W. (1992). Propositional reasoning by model. *Psychological Review, 99*, 418-439.

Lewicka, M. (1989). Toward a pragmatic perspective on cognition: Does evaluative meaning influence rationality of lay inferences? *Polish Psychological Bulletin, 20*, 267-285.

Lewicka, M. (1992). Pragmatic reasoning schemata with differing affective value of a consequent of logical implication. *Polish Psychological Bulletin, 23*, 237-252.

Mackie, J. L. (1965). Causes and Conditions. *American Psychological Quarterly, 2*, 245-264.

O' Brien D. P. & Davidson, G. M. (1989). Evaluation of evidence for sufficiency, necessity and for necessity-and-sufficiency. *Quarterly Journal of Experimental Psychology, 41,* 531-551.

Politzer, G. & Bourmaud, G. (2002). Deductive reasoning from uncertain conditionals. *British Journal of Psychology, 93,* 345-381.

Pollard, P., & Evans, J. St. B. T. (1980). The influence of logic on conditional reasoning performance. *Quarterly Journal of Experimental Psychology, 32*, 605-624.

Siegler, R. S. (1976). The effects of simple necessity and sufficiency relationships on children's causal inferences. *Child Development, 47*, 1058-1063.

Schroyens, W., Schaeken, W., & d'Ydewalle, G. (2001). The processing of negations in conditional reasoning: A meta-analytic case study in mental model and/or mental logic theory. *Thinking and Reasoning, 7,* 121-172.

Schroyens, W., Verschueren, N., Schaeken, W., & d'Ydewalle, G. (2000). Conditional reasoning with negations: Implicit versus explicit affirmation or denial and the role of contrast classes. *Thinking and Reasoning, 6,* 221-251

Thompson, V. A. (1994). Interpretational factors in conditional reasoning. *Memory & Cognition, 22 (6)*, 742-758.

Thompson, V. A. (2000). The task-specific nature of domain-general reasoning. *Cognition, 76, 209-268.*

Thompson, V. A. & Mann, J. M. (1995). Perceived necessity explains the dissociation between logic and meaning: the case of 'only if". *Journal of Experimental Psychology, Learning, Memory, and Cognition, 21,* 1554-1567.

Vanquickenborne, M. (1969). An analysis of causality in everyday language. *Logique et Analyse, 12,* 311-328.

Verschueren, N., Schroyens, W., Schaeken, W., & d'Ydewalle, G. (2004). *Necessity and Sufficiency in Abstract Conditional Reasoning.* Manuscript submitted for publication.

Waldmann, M. R. & Hagmayer, Y (2001). Estimating causal strength: The role of structural knowledge and processing effort. Cognition, 82, 27-58.

NOTES

1. The interdefinable definitions, such as *A is a sufficient condition for B, if and only if the absence of A is a necessary condition of the absence of B*, are not taken into account. We also take distance from the discussion whether participants understand the concept of logical necessity (as in necessity implies possibility but not vice versa).
2. For non-sufficiency, 5 participants said that although the cause cannot bring along the effect by itself, the cause is a necessary precondition for the effect. For non-necessity, 8 participants explicitly stated that there were alternative causes that could bring about the effect and one participant wrongly explained non-sufficiency by saying that the only way to obtain the effect is to prevent the cause from occurring. For non-necessity there were two answers that could not be linked to the cause-effect combinations: For non-necessity both answers came down to the same: 'the effect occurs by itself, with or without a cause'.

ABSTRACTS

Necessity and sufficiency are two central concepts in the literature on causal reasoning. Three experiments are reported that investigate how people understand these two concepts. It is found that necessity is more a complex notion than the notion of sufficiency. For sufficiency, people only verify whether the cause is always followed by the effect, whereas for necessity, there are two possibilities that can be verified: 'does the cause always precede the effect' and 'can the effect occur without the cause'. More importantly, it is found that both concepts have a different structure: necessity is considered as an all-or-none property whereas sufficiency is a more liberal characteristic. The present findings highlight the need for an appropriate operationalisation for measuring the perceived necessity and sufficiency of given cause-effect relations.

La nécessité et la suffisance sont deux concepts centraux de la littérature consacrée au raisonnement causal. Trois expériences analysant la manière qu'ont les individus de comprendre ces deux concepts sont exposées dans cet article. Les résultats indiquent que la nécessité est une notion plus complexe que celle de suffisance. Pour la suffisance, les sujets vérifient seulement si la cause est suivie de l'effet, alors que pour la nécessité, deux possibilités peuvent être examinées:"la cause précède-t-elle toujours l'effet?"et "l'effet peut-il apparaître sans la cause ?". Plus important encore, ces deux concepts manifestent une structure différente: la nécessité est considérée comme une propriété de type tout ou rien alors que la suffisance est vue comme une propriété plus graduelle. Les résultats soulignent l'utilité d'une opérationnalisation appropriée afin de mesurer la nécessité et la suffisance telles qu'elles sont perçues par les individus.

INDEX

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