Order Bias and the Suppositional Disjunction

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Abstract

We present a suppositional theory of disjunctive reasoning that proposes that 'either-or', like 'if', triggers hypothetical thinking. However, disjunctions are more complex as they require the reasoner to consider two hypotheses, violating the singularity principle. Hence one of the disjuncts becomes focal – the first one in the absence of conversational cues. As predicted, participants presented with disjunctive statements and asked to fill in a 6x6 grid with verifying combinations, tended to overrepresent TF cases. The results are discussed in terms of dual processing theories of reasoning and decision making.

Keywords: reasoning; disjunctions; conditionals; focal vs. residual hypothesis; suppositional

Introduction

Disjunctions, the 'either-or' logical connective, are ubiquitous in life. Choices are by nature disjunctive: you can either vote or not vote, you can't do both. We can promise or threat with disjunctions: 'Either come to work on time or you'll be fired'. We can regulate and set rules: 'members must have either a PhD or ten years experience'.

Though useful, 'or', that small innocuous-seeming word, also lies at the root of many a fallacy, illusion and paradox of reasoning and decision-making. It is much more difficult to learn disjunctive concepts and definitions (Bruner, Goodnow, & Austin, 1956; Wason & Brooks, 1979); reasoners are at a loss to make decisions when they face disjunctive events (Tversky & Shafir, 1992); and probabilities of disjunctive statements add up to too much or too little (Tversky & Koehler, 1994). Many notoriously difficult inferences have disjunctive structure: model theory's illusory inferences (Johnson-Laird & Savary, 1999); hypothetical thinking theory's collapse illusion (Elqayam, 2005); paradoxes of decision theory (Allais, 1953; Ellsberg, 1961). All are acknowledged, partially-acknowledged, or unacknowledged disjunctions (See also Shafir, 1994).

The research reported in this paper is part of a project designed to launch a new research programme to study the nature of disjunctive thinking and decision-making. We propose a theoretical framework that brings together previous disparate efforts in deductive reasoning, decision-making and inductive inference. This involves generalisation of the suppositional theory of the conditionals (Evans & Over, 2004) to disjunctive as well as conditional statements.

The heuristic-analytic theory of reasoning postulates three basic principles (Evans, 2005; Evans, Over, & Handley, 2003): singularity, relevance, and satisficing. The heuristic system (also known as system 1) operates preconsciously to generate representations of possibilities, or mental models, which are relevant in the current context (*relevance* principle). By default these will be the most plausible or believable possibilities. Only one model is generated for consideration at a time (*singularity* principle). These models are then assessed by the analytic system – slow, sequential conscious reasoning which is related to working memory capacity and IQ, also known as system 2. This is the system involved in hypothetical and consequential thinking. Finally, according to the *satisficing* principle models are accepted as the basis for inference and decisions if they satisfy with respect to the current goals of the reasoner. If not, another model is generated for consideration.

We propose that conditionals are suppositional in that they stimulate hypothetical thought about a particular hypothesis specified by the antecedent. The suppositional theory proposes that people evaluate a conditional statement by use of the extended Ramsey test (see Evans & Over, 2004). That is, they conduct a thought experiment or mental simulation in which p hypothetically holds, making the least possible change needed to accommodate it. The conditional is then believable to the extent that q is probable in this mental simulation. A number of recent studies have provided evidence that in general people do assign the conditional probability P(q|p) when asked to judge the probability of a conditional (Evans, Handley, & Over, 2003; Hadjichristidis et al., 2001; Oberauer & Wilhelm, 2003; Over, Hadjichristidis, Evans, Handley, & Sloman, 2005).

We suggest that disjunctions, p or q, are also suppositional in that they invite the listener to consider two alternative hypotheses. However, since people only consider one at a time (singularity principle) evaluation of disjunctions is more complex. We need mentally to simulate the p disjunct, store the result, and then simulate the q

disjunct and compare the results. Limitations in processing capacity are likely to bias this process in ways we propose below. We expect that disjunctions like conditionals will be probabilistic in the sense that they are believable to some degree. This must be to some extent a function of the believability of its disjuncts but little previous research has addressed this relationship.

How, then, do we deal with disjunctions? One possibility is that reasoners allocate asymmetric weights to the competing hypotheses. Support theory (Tversky & Koehler, 1994) distinguishes between focal hypotheses, which have greater 'support value' – i.e., strength of evidence in its favour – and alternative or residual hypotheses, whose support value is lower. With disjunctions in everyday life, which contain conversational cues, we are generally adept at picking out the focal disjunct, using our knowledge of context, the speaker, and our beliefs, goals and preferences.

With abstract materials, our surmise is that the default focal hypothesis, in the absence of conversational cues, would normally be the first disjunct. There is some evidence for this hypothesis from previous research (Evans, Legrenzi, & Girotto, 1999): when asked to choose cases that would verify a disjunctive rule of the type 'either p or q' (e.g., 'either D or 3'), participants tended to choose TF (True-False) cases more than FT (False-True) cases (e.g., more D4 cases than G3 cases). The effect was even more pronounced when participants had to construct the cases themselves: 33% constructed TF cases, whereas only 8% constructed FT cases (Evans et al., 1999, experiments 3 and 2 respectively). This systematic bias towards the first disjunct is distinctly non-logical: there is no logical reason to prefer either disjunct.

However, focusing attention on one disjunct is a product of the heuristic, rapid, automatic system. Order bias, then, may be restricted to early representation, with reasoners later on drawing on the analytic system to construct equi-probable representation of both disjuncts. There are some indications for this in the literature. In a similar truth-table construction task (Evans & Newstead, 1980, Experiment 1), an inspection of the data reveals clear order bias in the letter-number pairs participants constructed in their first response, but when participants proceed to construct more pairs, the bias disappears. However, the attempt to engage the analytic system and re-construct representation of both disjuncts may not always meet with success, the result being the sub-additivity and super-additivity of disjunctive probabilities noted by support theory (Rottenstreich & Tversky, 1997; Sloman, Rottenstreich, Wisniewski, Hadjichristidis, & Fox, 2004; Tversky et al., 1994).

The experiment reported in this paper compares the subjective probability of abstract disjunctions and conditionals. In this experiment, we adopt the task of Evans, Ellis and Newstead (1996), who asked participants either to construct or evaluate arrays of coloured shapes with respect to conditionals such as 'if it is a triangle then it is red'. The symbols represented all logical possibilities: red triangle (pq), non-red triangle (p not-q), red non-triangles (not-p q)

and non-red non-triangles (not-p not-q). When asked to represent a true conditional, people include some counterexample (p not-q) cases thus setting P(q|p) to be high but less than 1. When asked to represent a false conditional, people included many such cases thus setting P(q|p) to be low. This suggests probabilistic representation, since logically there should be no 'p not-q' cases for a true conditional and simply one or more for a false conditional.

The Evans et al. (1996) task is a sensitive measure of probabilities, enabling us to test for relative frequency of either disjunct and hence for order bias. Thus, with disjunction of the form 'either p or q', p should be more often represented than q. For instance, if we ask our participants to construct an array representing the disjunction 'there is either a D or a 3', we would expect them to insert in their representation more cards with D than cards with 3. If we compare this with the conditional that corresponds to it in standard extensional logic, 'if there is not a D then there is a 3', however, our suppositional account makes precisely the reverse prediction. Here we expect not D and 3 cases to be more commonly represented since they constitutes a clear confirmation of the conditional, and D and not 3 cases to be much less frequent, as D cards are 'irrelevant' to the suppositional conditional (see Evans & Over, 2004).

We also included in this study exclusive disjunctives, e.g. 'there is either a D or else a 3'. These are equivalent in standard logic to a biconditional, 'if and only if there is not a D then there is a 3'. Although we did not expect these forms to be evaluated in the same way as inclusive disjunctives and conditionals, the same relative tendencies apply to both (see Table 1 for a full set of sentences and predictions). Of the four forms, exclusive and inclusive disjunctions, and conditionals and biconditionals, only conditionals have previously been studied in this paradigm.

Participants were presented with 8 tasks (ordered randomly) involving each of the linguistic forms shown in Table 1, in a mixed design. In each case they were asked to fill a grid of 36 squares with a mixture of symbols representing the pq, p not-q, not-pq and not-p not-q possibilities in order to make the statement true.

The predictions were:

Order bias hypothesis: we expected the first-named disjunct to be represented more frequently than the second-named disjunct for both kinds of disjunctive statements; and for true antecedent cases to be represented more frequently than false antecedent cases for both kinds of conditionals, leading to the specific set of predictions shown in Table 1.

The auxiliary prediction, initial response hypothesis, was that order bias would be stronger for initial or first responses and disappear, or nearly so, for later responses.

Probabilistic representation hypothesis: for data taken from the whole grid, we expected some inclusion of cases which would logically falsify the statements. This would generalise the results of Evans et al. (1996) to several new linguistic forms. These cases are as follows: Conditional statements: TF; biconditional statements: TF, FT; inclusive

Table 1: Order bias predictions

	Comparison 1 **Inclusive disjunctions vs.** **conditionals**	**Comparison 2** **Exclusive disjunctions vs.** **biconditionals**	**Predicted case** **frequencies**
disjunction	p or q	p or-else q	p not-q > not-p q
conditional	if not-p then q	If-and-only-if not-p then q	p not-q < not-p q
disjunction	not-p or q	not-p or-else q	not-p not-q > p q
conditional	if p then q	If-and-only-if p then q	not-p not-q < p q

disjunctives: FF; exclusive disjunctives: TT; FF.

Disjunctive format hypothesis: We expected more TT cases to be represented for inclusive disjunctions (either p or q) than for exclusive disjunctions (either p or else q).

Conditional format hypothesis: We expected conditionals ('if p then q') to be represented according to the 'defective conditional' pattern (see Evans & Over, 2004), that is, we expected TT cases to be evaluated as T, TF to be evaluated as F, and both false antecedent cases to be evaluated as irrelevant, or I (abbreviated as TFII). The biconditionals ('if and only if p then q') we to be represented in line with the 'defective biconditional' pattern, TFFI. However, the method used in our study cannot distinguish between this and the defective conditional pattern, TFII, since if FT cases are not generated this may be because they are considered false or because they are not considered relevant. Therefore, we left this as an exploratory question to see whether any differences would come up.

METHOD

Participants. 39 students of the University of Plymouth participated on a paid volunteer basis and were tested in small groups. All participants were native speakers of English and none of them had had formal training in logic.

Materials and Procedure. We used the number-letter combinations in the eight linguistic forms shown in Table 1, twice for each cell, a total of 16 trials, in one of eight different random orders, presented in a booklet. Each page

consisted of a statement and a 6x6 grid. Participants were instructed to fill in the grid with letter-number pairs to make the statement 'true with respect to the appearance of the grid'. They were told that they were free to use any pair as often or as little as they wished, as long as the grid was completely filled in. A practice trial with a negated conjunction preceded the actual test materials. Participants were given the trials in two blocks of eight statements consisting of the different linguistic forms in Table 1.

Design. We used a 2x2x4 mixed design, with within participants variables of linguistic forms (exclusive and inclusive disjunctions, conditionals and biconditionals), and affirmative vs. negated first term. We also had letter-number vs. number-letter as a between participants variable: a random half of the participants were presented with statements such as 'Either K or 4', and the other half with statements such as 'Either 9 or B'. This controlled for a possible confound of preference to letter-number over number-letter combinations.

RESULTS AND DISCUSSION

Since there were no significant differences in preference patterns between the letter-number / number-letter conditions, data from these conditions were pooled.

Initial response data

Table 2 presents response frequencies for initial responses, i.e., responses in the topmost left-hand cell of the grid. As can be seen, our *order bias hypothesis* was strongly supported: all disjunctions display marked preference to TF

Table 2: % of Initial responses (top left cell). Logical case in parenthesis. Examples in italics.
Cells corresponding to order bias hypothesis in bold (for disjunction: TF>FT; for conditionals: TT>FF)

	TT	TF	FT	FF		TT	TF	FT	FF
Disjunctions					**Conditionals**				
p or q	0 (pq)	**74** (p¬q)	19 (¬pq)	6 (¬p¬q)	**if not-p then q**	60 (¬pq)	3 (¬p¬q)	1 (pq)	**36** (p¬q)
D or 3	*D3*	*D5*	*E3*	*E5*	*if not- D then 3*	*E3*	*E5*	*D3*	*D5*
p or else q	1 (pq)	**79** (p¬q)	19 (¬pq)	0 (¬p¬q)	**iff not-p then q**	55 (¬pq)	8 (¬p¬q)	6 (pq)	**31** (p¬q)
B or else 6	*B6*	*B8*	*C6*	*C8*	*iff no- B then 6*	*C6*	*C8*	*B6*	*B8*
not-p or q	19 (¬pq)	**51** (¬p¬q)	1 (pq)	28 (p¬q)	**if p then q**	65 (pq)	1 (p¬q)	3 (¬pq)	**31** (¬p¬q)
not-K or 2	*L2*	*L3*	*K2*	*K3*	*If K then 2*	*K2*	*K3*	*L2*	*L3*
not-p or else q	42 (¬pq)	**27** (¬p¬q)	6 (pq)	25 (p¬q)	**iff p then q**	69 (pq)	0 (p¬q)	0 (¬pq)	**31** (¬p¬q)
not-F or 9	*E9*	*E4*	*F9*	*F4*	*Iff F then 9*	*F9*	*F4*	*E9*	*E4*
Total	16	**58**	12	15	**Total**	62	3	3	**32**

Table 3: Mean % of whole-grid responses. Logical case in parenthesis.
Cells corresponding to order bias hypothesis in bold (for disjunction: TF>FT; for conditionals: TT>FF)

Disjunctions	TT	TF	FT	FF	Conditionals	TT	TF	FT	FF
p or q	1 (pq)	**48** (p¬q)	**43** (¬pq)	8 (¬p¬q)	if not-p then q	**51** (¬pq)	9 (¬p¬q)	2 (pq)	**38** (p¬q)
p or else q	0 (pq)	**49** (p¬q)	**44** (¬pq)	6 (¬p¬q)	iff not-p then q	**51** (¬pq)	14 (¬p¬q)	2 (pq)	**32** (p¬q)
not-p or q	25 (¬pq)	**55** (¬p¬q)	**1** (pq)	19 (p¬q)	if p then q	**32** (pq)	1 (p¬q)	6 (¬pq)	**61** (¬p¬q)
not-p or else q	37 (¬pq)	**33** (¬p¬q)	**4** (pq)	25 (p¬q)	iff p then q	**29** (pq)	3 (p¬q)	2 (¬pq)	**65** (¬p¬q)
Total	16	**46**	**23**	15	Total	**41**	7	3	**49**

over FT cases. If we compare that to the conditionals that are logically equivalent according to standard propositional logic, the parallel logical cases have the reverse preference, with TT cases preferred over FF cases (also see general discussion). [1]

To test the significance of these results, we have calculated an order bias index for each linguistic form. For disjunctions, we added 1 for each response that favoured the first disjunct (i.e., TF responses), and deducted one for each response that favoured the second disjunct (i.e., FT responses). A one-sample Wilcoxon Signed Rank test revealed that the median index for each of the disjunctive forms was significantly above zero (p<.01).

To compare order bias between disjunctions and conditionals, we computed order bias for the conditionals based on the same logical cases, FF and TT respectively. We added 1 for each FF response and deducted 1 for each TT response. A Sign test conducted for order bias index for all four comparisons revealed a significant result in each case (|z|>3.5, p≤.001).

It is also worth noting that we seem to get a very strong exclusive reading for most disjunctions – there are hardly any TT cases, in particular for the non-negated disjunctions. The disjunctions with a negated first term elicit more inclusive readings, in particular – paradoxically – the 'or-else' form. Also, there is a moderate biconditional reading of all conditionals, with about 30% FF responses. Actual linguistic format seems to have had very little effect – there seem to be no differences between 'if' and 'if and only if' formats. Thus, our *disjunctive and conditional format hypotheses* were not supported.

Lastly, there seems to be an effect of negation dropping in the disjunctions (Evans, Newstead, & Byrne, 1993). This is a known and robust effect, in which participants tend to ignore the negation and treat, for instance, 'Either not-B or 3' as if it were 'Either B or 3'. If the negation is dropped what is intended as a TF case comes out as an FF case. This explains the high rate of FF cases found in both negated disjunction forms. Taken in this light, some TT responses

for negated disjunctions may not indicate an inclusive reading, but simply FT responses.

Whole grid data
Data calculated for the whole grid are presented in Table 3. (Note that the data are not entirely independent from the initial response data but we felt that the overlap, 1/36, was narrow enough to justify the separate treatment. Also note that these are mean percentages of whole-grid distributions, rather than the one-cell percentages presented for initial responses.)

The most important observation is that, in line with our auxiliary prediction, the *initial response hypothesis*, order bias seems to have disappeared from some of the disjunctions. Specifically, it was only preserved for disjunctions with negated first term. To test this observation, we computed again a bias index along the same lines we computed the index for initial responses. For the disjunctions, we added a point for each response favouring the first disjunct (TF responses), and deducted a point for each response favouring the second disjunct (FT responses). To compensate for missing data the index was converted to proportions. These we tested again using one sample Wilcoxon Signed Rank test against a median of 0. Neither affirmative disjunction differed significantly from zero (p>.1), although both negated disjunctions did (p<.0001).

Even for the negated disjunctions, we would be hard put to claim order bias, since they did not differ reliably from the equivalent conditionals. For the conditional order bias index, we added a point for FF responses and deducted a point for TT responses, again converting to proportions. We contrasted the negated disjunctions with the non-negated conditionals, using related samples Wilcoxon Signed Rank tests. The results of these tests were equivocal: 'not-p or q' differed from 'if p then q' marginally, or significantly only in one-tail, z=-1.7, p=.087; 'not-p or else q' did not reliably differ from 'iff p then q', p>.1. Hence, there is no reliable, consistent data to support order bias in the whole grid responses, as we predicted in our initial response hypothesis.

Several other effects are worth noting. One is the striking biconditional reading in this dataset, especially for the non-negated forms, where it is so strong that there are actually more FF responses than TT responses. As in the initial

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[1] All data reported, here and elsewhere in this study, is aggregated. Although we recognise the importance of individual analyses for this dataset, it is beyond the scope of the present paper.

responses, the linguistic format, 'if' vs. 'if and only if', seems to have had very little effect, giving little support to our *conditional format hypothesis*. Secondly, the strong exclusive interpretation we have observed in the initial responses is preserved in the whole grid data, again mitigated somewhat for the negated forms, with the same paradoxical effect of the or-else format, lending little support to our *disjunctive format hypothesis*. So for this dataset too, neither of our format hypotheses was supported, an interesting finding by itself.

We should also point out the same negation dropping trend we have already noted for the initial responses, with a large proportion of FF responses in the negated disjunctions. Lastly, our *probabilistic representation hypothesis* was clearly supported, with quite a few TF cases for conditionals, and many FF cases for disjunctions. We shall return to this effect in the general discussion.

General Discussion

In this paper we present a new theory of disjunctive reasoning that proposes that disjunctions, like conditionals, are suppositional, and that 'either-or', like 'if', triggers hypothetical thinking. However, disjunctions are more complex as they require the reasoner to consider two hypotheses, violating the singularity principle (Evans, 2005; Evans et al., 2003). Hence one of the disjuncts becomes focal (Tversky & Koehler, 1994) and overrepresented. In the absence of conversational cues, this would be the first disjunct. Our theory is that the heuristic, rapid system first focuses on one disjunct, which is the first one when abstract disjunctions are involved. When reasoners are allowed more time, they engage the analytic system to attempt fill in representation of the residual disjunct – the second one in case of abstract disjunctions. This attempt may or may not succeed, depending on the complexity of the disjunctive representation.

To test this we have presented our participants with abstract disjunctive and conditional statements such as 'there is either a T or a 6', and 6x6 grids which we asked them to fill with combinations that would make the statements true. Our main prediction was for an order bias effect for disjunctions, in particular for initial responses, defined as the topmost left cell in the grid. We predicted that for disjunctions, TF cases would be represented more than FT cases, whereas for the equivalent logical cases of conditionals the opposite would be true. We also predicted that the effect would be attenuated for whole-grid representations. These predictions were fully supported: we have found strong order bias for initial responses, which all but disappeared for whole-grid data. The marginal order bias effects that remained for whole-grid data were restricted to disjunctions with negated first term, which are more complex. This supports our theoretical analysis that filling in representation of the residual disjunct necessitates an involvement of the analytic system.

Our account would not be complete without reflecting on possible alternative explanations by the popular theory of reasoning, mental model theory (Johnson-Laird & Byrne, 1991; 2002). The idea that initial representations differ from later ones has deep roots in model theory's account of 'fleshing out' representations (Johnson-Laird et al., 1991), although not with a dual-process account. In mental model theory, the initial mental model of a disjunction, 'p or q', looks like this:

$$p$$
$$q$$

where each line denotes a separate mental model. This initial partial representation is later 'fleshed out' – made more explicit – either as inclusive disjunction ('p or q')

$$p \qquad q$$
$$p \qquad \neg q$$
$$\neg p \qquad q$$

or exclusive ('p or else q')

$$p \qquad \neg q$$
$$\neg p \qquad q$$

Either way, model theory postulates symmetry between the disjuncts, which our findings do not support.

One possible way to keep order bias as compatible with model theory might be to supplement model theory with an adaptation of the principle of minimal completion (e.g., Ormerod, 2000; Ormerod & Richardson, 2003), which introduces the notion of partially represented models. When reasoners rephrase linguistic forms, they first create an initial model set (which corresponds to the initial set suggested by model theory), then use it to generate the first component of the rephrasing, only then completing the initial model set, and that only to the point of representing a second possible component of the rephrasing (Ormerod, 2000, p. 137). The partial representation minimal completion postulates only pertains to the second phase, when reasoners begin paraphrasing. However, an adapted version, in which the principle is extended to first representations, could account for some of our findings, both the initial order bias and its subsequent mitigation.

Although this is a possibility, there are several cautions to bear in mind. One is that the adaptation required would be quite fundamental. Initial representations in mental model theory are conceptualised as true literals within true possibilities (Johnson-Laird et al., 1999p. 194); the idea that some of these true literals may be left out of the first representation is a radical departure from this basic principle, and one, furthermore, that has not been originally suggested by minimal completion.

Secondly, although a modified version of minimal completion may account for our findings concerning order bias, it cannot account for the whole pattern. In particular, it cannot account for the probabilistic representation and the inclusion of falsifying cases when asked to generate confirmatory ones. This is diametrically opposed to the model theory's principle of truth, which maintains that only true possibilities are represented (Johnson-Laird & Byrne, 2001; Johnson-Laird & Savary, 1999).

The research we have presented in this paper is a first step in a research programme into the suppositional disjunction.

We still have to extend our enquiry, firstly into more aspects of abstract disjunctions. For example, if our dual-process account is correct, we would expect TF combinations to have lower latencies than FT combinations, when reasoners are presented with an evaluation task. More importantly, we need to study disjunctions in conversational context, and find out more on the pragmatic implicatures that guide speakers and listeners when they pick out a focal disjunct.

Although disjunctives are ubiquitous in everyday discourse, the amount of effort dedicated to them in the reasoning literature is paltry in comparison to the amount of research on conditionals. However, such effort is well worth the price as disjunctions can teach us further about the way in which heuristic and analytic processes interact. In this paper we have made a first step in this direction.

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