Negations in syllogistic reasoning: evidence for a heuristic-analytic conflict.

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Abstract

An experiment utilising response time measures was conducted to test dominant processing strategies in syllogistic reasoning with the expanded quantifier set proposed by Roberts (2005). Through adding negations to existing quantifiers it is possible to change problem surface features without altering logical validity. Biases based on surface features such as Atmosphere, Matching and PHM (Wetherick & Gilhooly, 1995; Chater & Oaksford, 1999) would not be expected to show variance in response latencies, but participant responses should be highly sensitive to changes in the surface features of the quantifiers. In contrast, according to analytic accounts such as mental models theory and mental logic (e.g., Johnson-Laird & Byrne, 1991; Rips, 1994) participants should exhibit increased response-times for negated premises, but not be overly impacted upon by the surface features of the conclusion. Data indicated that the dominant response strategy was based on a matching heuristic, but also provided evidence of a resource demanding analytic procedure for dealing with double negatives. The authors propose that dual-process theories offer a stronger account of these data whereby participants employ competing heuristic and analytic strategies and fall back on a heuristic response when analytic processing fails.

Introduction

In the study of deductive reasoning, the syllogism continues to be a useful test-bed for theories of deduction (e.g., Stupple & Ball, 2007). The competing theoretical accounts of deduction have tended to emphasise explanations of the analytic mental processes and representations through which deduction occurs – e.g., Mental Models and Mental Logic (Johnson-Laird & Byrne, 1991; Rips, 1994), or explanations which argue that participants respond to deductive reasoning tasks by applying non-logical heuristics to the surface features of problems – e.g., the

Probability heuristics model (PHM) and 'matching' (Chater & Oaksford, 1999; Wetherick & Gilhooly, 1995).

Mental models theory posits an analytic account of deduction in the form of three processing stages: comprehension , description and validation stage. Putative conclusions are compared with alternative models of the premises, and if no counterexample can be found then conclusions are accepted as valid (Johnson-Laird & Byrne, 1991). Mental models theory argues that sources of difficulty in syllogistic reasoning are due to the number of possible models that can be considered at the validation stage and also the figure of the syllogism at the description stage. Both these sources of difficulty are argued to burden working memory and therefore increase the likelihood of errors.

Mental logic theorists present a rival analytic account (e.g., Rips, 1994) that argues for deduction as a central cognitive facility, and suggest that formal rules of inference manipulate symbolic representations at the core of our cognitive architecture. These mental rules are applied in order to generate an internal, mental proof of a conclusion in the form of propositions and suppositions and, thus, make a valid deduction. The source of difficulty in mental logic theories is dependent on the number of rules required to complete the proof – the greater the number of rules the greater the demand on working-memory, and thus the greater the propensity for error.

Surface feature theories can be contrasted to these theories of analytic processes for deduction. For example, Wetherick (1989, Wetherick & Gilhooly, 1995) argued for 'matching' as an explanation of syllogistic performance whereby participants select conclusions such that the quantifier is the same as one in the premises. Wetherick argues that participants will select the 'most conservative quantifier' (i.e. the one that accounts for the fewest entities No< Some are not< Some < All) and are more inclined to match when both premises feature the same quantifier. However, Wetherick (1989) points out that matching is not a method of

successfully solving syllogisms, but is instead a strategy that avoids the effort of doing so logically. He also argues that it is not adopted by all participants, and concedes that it may not even be applied by any participant all of the time. It is noteworthy that the matching heuristic proposed by Wetherick (1989) has been of considerable influence to the more recent probability heuristics account of syllogistic reasoning (Chater & Oaksford, 1999).

Chater and Oaksford (1999) proposed the PHM of syllogistic reasoning arguing that participants solve syllogisms by engaging in a probabilistic judgement based on the quantifiers used. According to the PHM, when deriving syllogistic conclusions reasoners apply various *heuristics* that involve minimal computational overheads (i.e., they are viewed as being 'fast and frugal' in the sense of Gigerenzer & Goldstein, 1996). The most important heuristic for the current paper is the '*min*-heuristic' which captures the principle that a conclusion will take the form of the least informative quantifier in the premises, effectively this is a refined version of the matching heuristic presented by Wetherick (1989).

Roberts (2005) presented a challenge to reasoning researchers by introducing an 'expanded universe of categorical syllogisms' through which to examine existing accounts of syllogistic reasoning. A novel set of materials was developed to flesh out the traditional set of syllogistic quantifiers by supplementing them with single and double negations. One of the most interesting properties of the expanded set of syllogisms is that by adding negations to existing premises it is possible to alter the surface features of a syllogism without altering its underlying logic. Investigating the effects of negation on reasoning dates back to Peter Wason's sentence-picture verification task (see Wason & Johnson-Laird, 1972), and has been popular in the context of propositional reasoning (e.g., Schroyens, Schaeken, Fias & d'Ydewalle, 2000), it has not previously been applied to syllogistic quantifiers (see Stenning, 2002 for an interesting exception to this). Therefore, a range of novel predictions for the expanded set of syllogisms can be derived from current theories of

syllogistic inference. The particular predictions that we are interested in here are those pertaining to the cognitive complexity of the quantifiers and also to the application of heuristic strategies such as matching. The goal of the present paper is to arbitrate between surface and analytic theories of deductive reasoning by employing negated syllogistic premises and traditional premises and measuring response-times and acceptance rates.

It is well established in the reasoning literature that negated premises are more complex in propositional reasoning (Evans, Newstead & Byrne, 1993) and are associated with an increased inspection-time (Schroyens et al., 2000). Predictions of similarly increased difficulty for double-negated premises in syllogistic reasoning come from within the mental models framework. For example, Johnson-Laird and Byrne (1989) presented syllogisms with the quantifier 'only' , arguing that 1) *only a's are b's* is logically equivalent to *all b's are a's*, and 2) that syllogisms presented with the quantifier 'only' are more demanding than those presented with 'all' because 'only' emphasises the negative information in the premise (given Johnson-Laird and Byrne's example *only criminals are psychopaths* it is apparent that those people who are not criminals are not psychopaths) and therefore participants flesh-out the model to represent positive and negative information, rendering it more complex. This argument extends to include premises with double-negations, and we argue that participants would be similarly induced to represent instances of both positive and negative individuals in their mental models. From this it can be predicted that participants will have increased response-times and produce more errors for the double-negated problems.

Mental Logic theorists explain the complexities that arise through double negations by specifying a mental rule that eliminates them (e.g., Rips, 1994). If participants require an additional mental rule to eliminate the double negations then we would expect increased response-times for those problems. However, if this rule is considered intuitive and basic then we would not expect a substantial decline in

performance (especially on simplistic reasoning problems requiring relative few rules). It is clear that equivalent predictions for both mental models and mental logic approaches can be made - therefore for the purposes of this paper they will be broadly characterised as ‘analytic accounts’.

Analytic accounts can be contrasted with heuristic accounts whereby fast and frugal rules of thumb are applied to *surface features* to derive or evaluate a conclusion, and do not predict a cognitive load associated with negated premises (e.g., Chater & Oaksford, 1999; Wetherick & Gilhooly, 1995). The proposal that participants respond to syllogisms by matching the quantifier in the conclusion to one of the premises has been tested, with contrasting results, using traditional syllogistic premises (e.g., Wetherick & Gilhooly, 1995) and also with the syllogisms using the quantifier ‘only’ (Johnson-Laird & Byrne, 1989), but has not yet been tested with the negations paradigm presented by Roberts (2005). Johnson-Laird and Byrne (1989) found evidence in opposition to the matching hypothesis by demonstrating that participants tended not to respond to premises including the quantifier ‘only’ with a conclusion including ‘only’. In contrast, Wetherick and Gilhooly (1995) demonstrated a matching strategy in a substantial sub-set of participants (25 out of 71) using traditional quantifiers. They also criticised Johnson-Laird and Byrne (1989) arguing that ‘only’ is systematically ambiguous and not widely regarded as a quantifier.

A strength of these double-negated syllogisms is that they allow for tests of the matching hypothesis without the potential for the logic of the premises to confound the responses (all premise pairs are logically equivalent and the only variation is on the basis of the surface features). Note also that according to Wetherick and Gilhooly (1995) these premise pairs will be particularly conducive to a matching strategy as both premises feature the same quantifier and that predicted responses from PHM will be identical for the same reason (Chater & Oaksford, 1999). In the context of deriving predictions for this experiment will be broadly construed as surface-feature theories that offer equivalent predictions.

Moreover, Gilhooly (2005) has argued that when cognitive loads increase the tendency is for participants to employ less cognitively demanding strategies such as matching, therefore it can be predicted that there will be an increase in the frequency of matching responses when the more demanding negated premises are presented.

We have argued that there is a contrast in predictions made by analytic and surface feature theories, and extend that argument to suggest that these accounts can be viewed as conflicting heuristic and analytic strategies within a dual process framework such as that espoused by Jonathan Evans (e.g., 2007, 2009). Evans (2007) argued for a default-interventionist theory, whereby heuristic responses are rapidly and routinely invoked, but with the opportunity for analytic processes to intervene to override heuristic responses. In contrast, in his more recent hybrid model, Evans argues for a preconscious 'type 3' process that can decide to respond heuristically without waiting for the analytic system to complete its process. Sloman's (2002) model proposes a further alternative - that heuristic and analytic processes can operate in parallel with the conflict between systems resolved by the analytic system once the analytic processing has been completed. These accounts make differential predictions for the experiment here. Both the default-interventionist and hybrid accounts suggest that where heuristic responses dominate there will be little evidence of analytic processing; in contrast the parallel account would predict that there would be evidence of analytic processing irrespective of the dominant response.

Finally, in terms of predictions relating to the validity of the syllogisms, it is argued that valid conclusions can be accepted as necessary without the exploration of falsifying models, whereas invalid conclusions require construction of an alternative falsifying model to be refuted (Hardman & Payne, 1995; Stupple & Ball, 2007), Mental Logic theories argue that it is more time consuming to attempt to construct a proof for a fallacy than a proof for a valid conclusion, Based on this evidence it is predicted that valid conclusions will be responded to more accurately

and with lower response-times than invalid conclusions. The mental logic explanation for such an effect would be that it is more time consuming to attempt to prove a false conclusion than to prove a true one.

In order to examine these competing hypotheses an experiment was conducted to examine response-times and acceptance rates on a conclusion evaluation task in which participants were presented with traditional and negated premises and conclusions.

Method

Participants

Fifty-six University of Derby Undergraduate students were recruited. Participants were aged between 19-45 years. None had prior knowledge of reasoning research. Three participants were excluded as they did not complete all of the tasks.

Design

The study used a repeated measures design. Premise surface features (double-negated versus traditional), Conclusion surface features (double-negated versus traditional) and Validity (valid versus invalid) were manipulated. The dependent measures were conclusion-acceptance rates and response-times for the presented syllogisms.

Materials

16 one-model syllogisms were presented (in figures AB-BC and figure BA-CB). These were presented with valid or invalid conclusions and either with traditional quantifiers or with expanded quantifiers (Roberts, 2005). According to Robert's notation they were in the moods A[aa] A[aa] and N[an] N[an]: *All A are B, All B are C* versus *No A are not B, No B are not C.* Conclusions were either congruent (both premises and conclusions were traditional or both were negated) or

incongruent with the presented premises (such that traditional premises were presented with negated conclusions and negated premises were presented with traditional conclusions). See table 1 for details.

(Insert table 1 here)

The content of all syllogisms was neutral, and involved arbitrary combinations of professions and pastimes. Problems were counterbalanced and content was systematically rotated through the different problem forms. Authorware 5.1 running on Windows PCs was used to present instructions and problems and to record responses and response times.

Procedure

Participants were presented with the following computer-based instructions: "This is an experiment to test people's reasoning ability. You will be shown 16 reasoning problems. For each problem there will be three masked statements. These will be labelled 'Premise 1', 'Premise 2' and 'Conclusion'. By clicking your mouse on the masked areas you can reveal the statements. For each problem you are asked if the conclusion given below the premises may be logically deduced from them. You should answer this question on the assumption that the two premises are, in fact, true. You may revisit each of the three masked areas as many times as you wish although you cannot view more than one area simultaneously. [An example problem was presented at this point]. If, and only if, you judge that the conclusion necessarily follows from the premises, you should click 'Yes'; if you judge that it does not necessarily follow you should click 'No'. Please take your time and be sure that you have the right answer before giving your response. After each trial a box will appear saying 'Click to continue'. Do this when you are ready to proceed.

Results

A threshold alpha level of .05 was set for the analyses.

Conclusion Acceptance Rate

A repeated measures analysis of variance was conducted on conclusion acceptance rates. Data reliably indicated that more traditional conclusions were accepted than negated conclusions (F (1, 52) = 6.77, MSE=.13, p = .012, η_p^2 =.12), . There was a near significant effect of Validity F (1, 52) = 3.95, MSE=.14, p =..052, η_p^2 =.07, such that there were higher acceptance rates for valid conclusions than invalid conclusions.

(Table 2 here)

However, the most clear-cut finding was a reliable interaction between Premise Format and Conclusion Format, F (1, 52) = 17.23, MSE= .16, p< .001, η_p^2 = .25, whereby the highest conclusion acceptance rates were found when the premises and the conclusion were congruent, with substantially reduced acceptance rates when premises and conclusions were incongruent. Specifically, post-hoc tests (Bonferroni adjustment) showed that fewer traditional conclusions were accepted for double-negated premises than for traditional premises (p=.003), more double negated conclusions were accepted for double negated premises than were for traditional premises (p=.001) and more conclusions were accepted when traditional premises were presented with traditional conclusions than double negated conclusions (p<.001).

No other effects or interactions were significant (p>.05). The next largest F-value was 3.08, however this was shown to have a small effect size (η_p^2 = .056).

Response-times

Finally, there was a weak, but, significant interaction between the premise format and conclusion format, F (1, 52) = 4.50, MSE= .02, p = .039, η_p^2 =.08, such that while problems with traditional premises tended to be inspected less than those with double-negated premises this difference was moderated by the congruence between the surface features of premises and conclusion.

(Insert Table 3 about here)

No other main effects or interactions were significant ($p>.05$). The next largest F-value was 1.79, however this was shown to have a trivial effect size ($\eta_p^2 = .033$).

General Discussion

The data presented here provide some support for predictions from both analytic and surface theories of deductive reasoning. The effect of negated premises on response times demonstrates a clear cognitive load induced by the negation paradigm; and is consistent with the predictions of the analytic accounts (e.g., Johnson-Laird & Byrne, 1991; Rips, 1994). However, it is incongruent with heuristic accounts based on surface features where cognitively demanding strategies should not be the dominant process. In contrast the interaction between premise format and conclusion format on response rates offers strong support for a heuristic process that matches surface features of premises to those presented in conclusions (Chater & Oaksford, 1999; Wetherick & Gilhooly, 1995). Note however, that this tendency was not significantly increased for more complex problems (in terms of negated premises or invalid conclusions), and does not offer support for Gilhooly's (2005) prediction that more simplistic strategies will be employed as the complexity of the task increases. In fact, the interaction suggests a stronger matching effect for Traditional premises (82% of Traditional conclusions accepted, 56% of Negated conclusions accepted) than for Negated premises (74% of Negated conclusions accepted, 67% of Traditional conclusions). These data are congruent with the notion that an increase in analytic processing results in a reduction in matching responses.

Acceptance rates did not show reliable evidence of logical competence - there was only a weak, near-significant, tendency for participants to identify valid conclusions at better than chance levels, Moreover, the fact that traditional conclusions were more readily accepted than negated conclusions may have indicated a general aversion to the negated conclusions, which suggests that a

proportion of the participants were unaware of the logical consistency between A[aa] A[aa] and N[an] N[an] conclusions. However, the lack of an interaction between validity and conclusion format suggests that neither the misinterpretation of All A are C as equivalent to All C are A, or a failure to translate double negated conclusion dominates as a source of error.

Mental models theory was congruent with the response-time data, assuming either that double negated premises induce the representation of negative instances that Johnson-Laird and Byrne (1989) argue occur for the quantifier 'only'. Moreover, models based predictions about conclusion validity and response-times were again replicated successfully. However, the data contradicted the mental models theorists claims in opposition to matching from Johnson-Laird and Byrne (1989) because acceptance rate data are very much supportive of this heuristic strategy.

Mental Logic theories fair similarly to mental models theory. The response-time data is readily accounted for because the double-negated premise require the application of a double-negation elimination procedure which adds another inference rule to the proof – which, in turn, would increase response-times for the task. Moreover, it is more time consuming to attempt to derive a proof for an invalid conclusion (as no proof exists) than it is to prove a valid conclusion. However, the acceptance rate data are similarly problematic as for mental models theory. Many participants would appear to be lacking a double-negation elimination rule which suggests that it is not an 'intuitively obvious deduction' Rips (1994, p. 112-113).

The surface feature accounts would appear to have the opposite problem – they can readily account for the broad trends in the acceptance rate data through the application of a matching or min heuristic, but struggle to account for the clear-cut impact of double negations on response-times - a quick and dirty heuristic process should not take longer to apply to either type of premise. Therefore the data would seem most readily accounted for with a dual process theory positing competing heuristic and analytic processes.

The data are most clearly supportive of Sloman's (2002) account whereby a matching/min heuristic response competes with (and defeats) the slower analytic process (which is engaged sufficiently to demonstrate systematic differences in response time between the formats to indicate the greater complexity for double negated premises, but not to win out over the heuristic response). Stupple and Ball (2008) presented evidence for a parallel dual process model for belief biased syllogisms using the methodology presented here that suggested that a belief-based heuristic and an analytic process proceeded in parallel competition.

There is little support for a default-interventionist account principally because the heuristic-analytic process advocated in this model appears reversed in the data presented here – the dominant process was analytic, but the dominant responses were heuristic. The Hybrid model presented by Evans (2009) receives some, albeit relatively weak, support in the current data set. This account suggests that where the heuristic response is given there will be little evidence of analytic processing (which was not the dominant process characterised here). Moreover, it would appear that the participants, if not engaging in processes competing in parallel, were prioritising analytic processing Nonetheless, there was some support for the notion of a preconscious conflict detection process - there were faster response times to the premises that matched their conclusions which would be expected if a preconscious process were selecting problems with a premise – conclusion mismatch as requiring further analysis. Note however, that this evidence in favour of the hybrid account needs to be considered with the caveat that this interaction had a small effect size ($\eta_p^2 = .08$).

In summary, these data demonstrated evidence of a matching/min heuristic dominating the responses in a conclusion evaluation task and evidence contradictory to that presented by Johnson-Laird and Byrne (1989) in dismissing matching as a significant response bias. The materials allowed the control of logic and matching independently, such that the matching heuristic could be observed without logic as a

confounding variable. Moreover, we argue that explanations based on surface features (matching or PHM) that do not include a substantial role (in more than a minority of participants) for a cognitively demanding analytic process - such as mental models or rules - are incomplete as explanations of the current data set. We argue instead that the data are best explained within a dual process framework. It is suggested that the evidence favours a hybrid account (Evans, 2009) or a parallel processing account (2002) rather than a default-interventionist theory (e.g., Evans, 2007). Further investigation is required to better arbitrate between parallel and hybrid accounts.

Furthermore the data presented here underscore the necessity of moving away from manipulating reasoning problem inputs and measuring the participant response outputs towards incorporating fine-grained process-tracing methodologies because the heuristic-driven response data reported here would otherwise conceal underlying analytic processing, and without acknowledging both we cannot present a full account of deductive reasoning.

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Table 1. Traditional and Negated Problem Materials.

	Traditional Premises		Negated Premises	
	Traditional Conclusion	Negated Conclusion	Traditional Conclusion	Negated Conclusion
Valid	All A are B All B are C Therefore All A are C	All A are B All B are C Therefore No A are not C	No A are not B No B are not C Therefore All A are C	No A are not B No B are not C Therefore No A are not C
Invalid	All A are B All B are C Therefore All C are A	All A are B All B are C Therefore No C are not A	No A are not B No B are not C Therefore All C are A	No A are not B No B are not C Therefore No C are not A

Table 2 *Percentage of Conclusion Acceptances as a Function of Premise Features, Conclusion Features and Conclusion Validity*

Conclusion validity	Traditional Premises			Negated Premises		
	Traditional conclusion	Negated conclusion	M	Traditional conclusion	Negated conclusion	*M*
Valid	89.6	59.4	74.5	66.0	78.3	72.2
Invalid	73.6	52.8	63.2	67.9	69.8	68.9
M	81.6	56.1	68.9	66.9	74.1	70.5

Table 2. *Mean response-times of problem components as a function of Premise Features, Conclusion Features and Conclusion Validity*

Conclusion validity	Traditional Premises						Negated Premises					
	Traditional conclusion		Negated conclusion		M		Traditional conclusion		Negated conclusion		M	
	ND	TD	ND	TD	ND	TD	ND	TD	ND	TD	ND	TD
Valid	13.52	11.64	15.51	13.40	14.52	12.52	19.22	16.22	18.63	15.10	18.93	15.66
Invalid	17.35	14.72	18.27	14.66	17.81	14.69	22.92	18.32	22.43	17.42	22.68	17.87
M	15.44	13.18	16.89	14.03	16.17	13.61	21.07	17.27	20.53	16.26	20.80	16.77

Note. ND = natural data in seconds. TD = transformed data (Log of natural data) converted into original measurement units (seconds). Standard errors for the natural data ranged from 1.10 to 2.68, and from 0.03 to 0.04 for transformed data. Standard errors have been omitted from the table to aid readability.